SOME FACTORS RELATING TO THE FEEDING HABITS OF GRASSHOPPERS

DISSERTATION

PRESENTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN THE GRADUATE SCHOOL OF THE OHIO STATE UNIVERSITY

BY

GEORGE SHEALY LANGFORD, B. S., M. S.

THE OHIO STATE UNIVERSITY

1929

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PREFACE

The data upon which this study is based were secured during the years of 1924 to 1927 while the writer was with the Colorado Experiment Station. The analysis and interpretation of the data and the preparation of the manuscript were completed at the Ohio State University under the guidance and supervision of Dr. Herbert Osborn, to whom I wish to make grateful acknowledgments for constant advice and encouragement. Appreciation and thanks for helpful criticisms and suggestions are due Dr. D. M. DeLong, Dr. C. H. Kennedy, Dr. Alvah Peterson and Dr. R. C. Osburn of Ohio State University, Dr. C. P. Gillette, Mr. Geo. M. List of the Colorado Experiment Station, and Dr. W. H. Larrimer of the U. S. Bureau of Entomology.

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SOME FACTORS RELATING TO THE FEEDING HABITS OF GRASSHOPPERS

By George S. Langford

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SOME FACTORS RELATING TO THE FEEDING HABITS OF GRASSHOPPERS WITH SPECIAL REFERENCE TO *MELANOPLUS BIVITTATUS*

By George S. Langford

These studies were made for the purpose of determining the effect of such factors as temperature, light, darkness and food plant upon grasshoppers, and their relation to control.

An intimate study of individual grasshoppers thru their life histories shows that temperature is apparently one of the most important factors regulating their rate of growth and daily activities, particularly the amount of food consumed daily. Such factors as light, darkness and the kind of food eaten appear to have little or no influence on the rate of development. The kind of food eaten determines the volume eaten and the number of times feeding occurs.

Normal activities occur between temperatures of 68 to 100 degrees F. A range of from 98 to 100 degrees in temperature appears to be the optimum. Grasshoppers react positively to this temperature range, and if maintained in it they will develop more rapidly and consume larger amounts of food than if maintained at a lower constant temperature. Temperatures above 105 degrees F. produce noticeable abnormal activities. Prolonged exposure to a temperature of 120 degrees F. will produce death. The physiological mechanism of grasshoppers is such as to carry them over relatively long periods without food or water when the temperature is low. At a low constant temperature of approximately 38 degrees F. they can live without food or water for a period of 192 to 240 or more hours, while at a constant temperature of 95 degrees F. death occurs in from 48 to 72 hours. By regulating the temperature under which a grasshopper is developing, the time required from the first instar to the adult may be varied from 30 days to more than 4 months. Grasshoppers moult from 5 to 7 times. Grasshoppers moulting the greatest number of times appear to be largest in size.

Grasshoppers apparently do not lay eggs when the air temperature is below 69 degrees F. or the soil temperature 65 degrees F. Egg laying has been observed to take place under rather variable moisture conditions, eggs being deposited in sandy soil when the soil moisture content varied from 9.77 to 20 percent.

When a temperature of 68 to 100 degrees F. is obtainable, feeding normally occurs thruout the entire day. The heaviest

feeding period occurs during the warmer portions of the day. This is indicated by the number of individuals feeding, the amount of food eaten, and the number of times feeding occurs. Normally, feeding does not cease during the hot portion of the day regardless of the temperature recorded by the weather-bureau method. If favorable, grasshoppers react to the environment where the temperature is at the optimum or nearly so and continue to feed.

The amount of food consumed daily per individual varies with the daily temperature. For lettuce it may vary from nothing at 55 degrees F. to 11.3 square inches for a 24-hour day at 95 degrees F. First instar nymphs eat from .02 to .14 square inches of lettuce each day depending upon the temperature and age of the grasshopper. As moulting takes place the amount of food eaten increases rapidly, in fact it almost doubles with each instar. Immature forms eat much less than adults. Adult females eat from 2 to 7.5 square inches of lettuce during a 12-hour day and on an average of 2.5 times more than males of the same species, under the same temperature conditions. Adult females eat daily more than 100 times as much as first-instar nymphs. There is considerable variation in the daily feeding activities. Individuals of the same brood vary in the amount eaten, also the same indviduals under apparently the same conditions vary from day to day. Both nymphs and adults in 24 hours eat 56.7 to 74.6 percent more food than in 12 hours if kept at a constant temperature of 95 degrees F. Age apparently does not affect the amount eaten by adult grasshoppers as long as they are active and are producing eggs or sperms.

When feeding upon different food plants, grasshoppers show an enormous difference in the amount they eat. This is true for all stages in their development. Normally they eat from 3 to 4 times as much lettuce as alfalfa per day. This variation may be accounted for to a certain extent by the dry-weight content of the plants. However, to account for the entire amount, it would appear that a knowledge of the exact extent to which a grasshopper is capable of digesting the nutrients of each material utilized, seems necessary.

Grasshoppers, normally, do not feed the day before moulting nor for several hours after.

The number of hourly periods in which a grasshopper eats during a day are few. The type of food determines this to a large extent. Individuals feeding upon lettuce average 5.7 feeding periods while those feeding on alfalfa average 3.2 for a 12-hour day.

Each feeding period is comparatively short. Sixteen minutes was the average for one period. Grasshoppers feeding on lettuce probably do not use over 3 hours a day, while those feeding on alfalfa probably do not use over 2 hours.

This kind of food plant apparently has no effect on the rate of development. Comparative studies show that grasshoppers reared entirely on lettuce completed 5 instars in approximately the same period of time as those reared on alfalfa.

Comparative studies indicate that light days of different lengths do not affect the rate of development as long as the temperature is constant.

Grasshoppers are capable of eating, growing and moulting in total darkness. When maintained under the same temperature conditions, development appeared to be as rapid in complete darkness as under normal day and night-light conditions.

The above-mentioned factors are closely associated with the abundance of grasshoppers in their normal environment from year to year and they also have a direct bearing upon control.

INTRODUCTION

Grasshoppers are world wide in their distribution. Evidence indicates that they have been a pest to agriculture since man began to till the soil. The writings of the Egyptians, Greeks and Ancient Hebrews contain references to these insects as pests to agriculture.

In Colorado conditions are usually favorable for grasshopper development, therefore the state always suffers more or less injury each season. It can be conservatively stated that grasshoppers cause greater losses to crops than any one other insect in the state.

Riley (60) states that since the year 1333, outbreaks have been recorded regularly. The literature is full of references concerning control. The following are a few of the control methods employed or recommended in the past: Prayer, making noises, using of soldiers, offers of bounties, poisonous plants, fire, crushing, collecting, spraying with poisons, destruction of eggs, use of turkeys, barriers, poisonous dusts and baits.

In America poisonous baits have proved the most successful type of control. However, there is a great difference in opinion as to the correct time for their application. Since the efficiency of the baits depends to a large extent on the time of application, it is of the utmost importance to know those factors which regulate the habits of grasshoppers, especially the feeding habits, in order that the use of baits may be effectively employed.

Figure 1.—Type of cage used in grasshopper experiments. (About one-half natural size.) This type of cage was used almost exclusively in studying individual hourly records A and B indicate method of feeding plants, with large leaves, as lettuce. The stems of the plants were kept in water.

The purpose of this investigation was to study the effects of such factors as temperature, light, darkness and food plant upon the development and general activities of grasshoppers. Special emphasis was placed on the factors which regulate feeding, the amount of food eaten, and the time of feeding for conditions in Colorado and at the same time to test the correctness of observations made by other workers.

The data thus far obtained and conclusions reached are believed to be of such a nature as to justify a report. Observations

were made over a 4-year period, 1924-1927, at Fort Collins, Colorado.

The author is indebted to Dr. C. P. Gillette and Mr. Geo. M. List for their encouragement, valuable suggestions and criticisms, and to J. L. Hoerner and S. C. McCampbell for valuable aid on many occasions.

METHODS OF EXPERIMENTATION

The present studies are based primarily on laboratory observations and supplemented with field observations, the individual grasshopper being taken as the unit of study. The reactions of the individual to various stimuli is the basis on which conclusions have been drawn.

A greenhouse and insectary were used as a laboratory for rearing except in those cases where the temperature cabinet was employed. The environmental data recorded are those in the immediate vicinity of the grasshopper. In the case of temperature, the readings were made inside the cage containing the grasshopper.

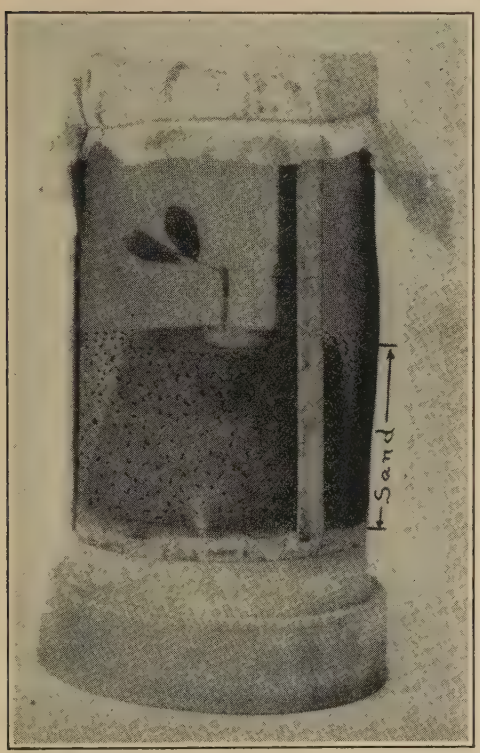

Fig. 2.—One type of cage used in the experimental work. (About one-half natural size.) Plant leaves are kept turgid by maintaining them in water as illustrated in Fig. 3.

Only one grasshopper was maintained in a cage. Cages of two different designs as illustrated in Figures 1 and 2 were employed. The cage illustrated in Figure 1 was a glass cylinder 8 inches in length and 2 and one-quarter inches in diameter, and was used for most of the work. The cage illustrated in Figure 2 was made by inverting a 4-inch flower pot over a bottle containing water. A cylindrical copper screen 8 inches in length and about 4 inches in diameter was fitted around the rim of the pot. The intervening space between the rim and bottom

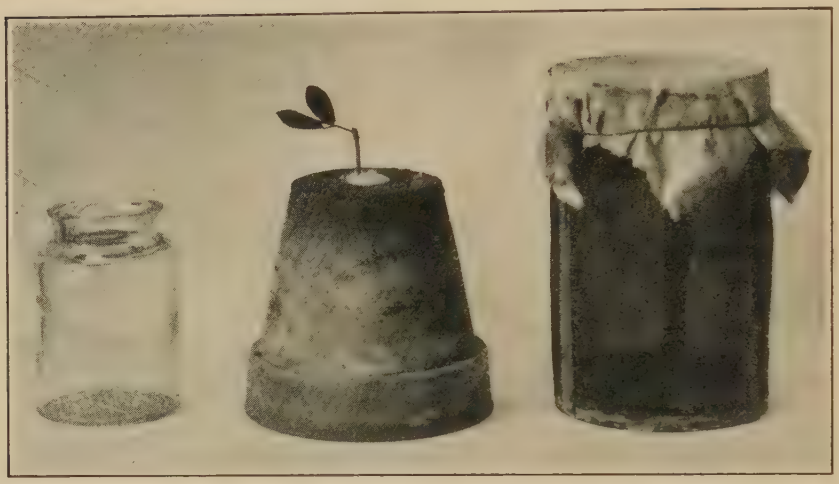

Fig. 2-A.—Showing unassembled parts of grasshopper cage illustrated in Fig. 2.

of the pot was filled with sand. The food plant was placed thru the drain in the bottom of the inverted pot, with its stem extended into the bottle of water beneath, and held firm by a cotton plug.

In the feeding investigations the grasshoppers were fed hourly on fresh leaves, the stems of which were kept in water. When plants having large or delicate leaves were fed, the leaves used were placed in a heavy cardboard or celluloid holder as illustrated in Figure 1. The surface area of the leaves was recorded before and after being fed, by a photo-print method. The difference between the surface areas calculated by the use of a planimeter was the amount eaten. To obtain an accurate reading of the amount eaten by the small nymphs, it was often necessary to enlarge the print by projecting it upon a screen placed upon a table.

The photo-prints were made by using either blueprint or Van-Dyke paper. The Van-Dyke paper has an advantage over the blueprint paper in that it can be readily photographed without being traced; also one can make blueprints from it. Figures 3 and 4 illustrate the method of printing and results obtained. Figure 5 represents the method of recording data.

Several methods were considered for recording results. The above was selected because of its simplicity and because it permitted the study of a larger number of individuals with the labor available. It also permitted a study of the actual leaf surface eaten. This, the writer felt, was significant, as grasshop-

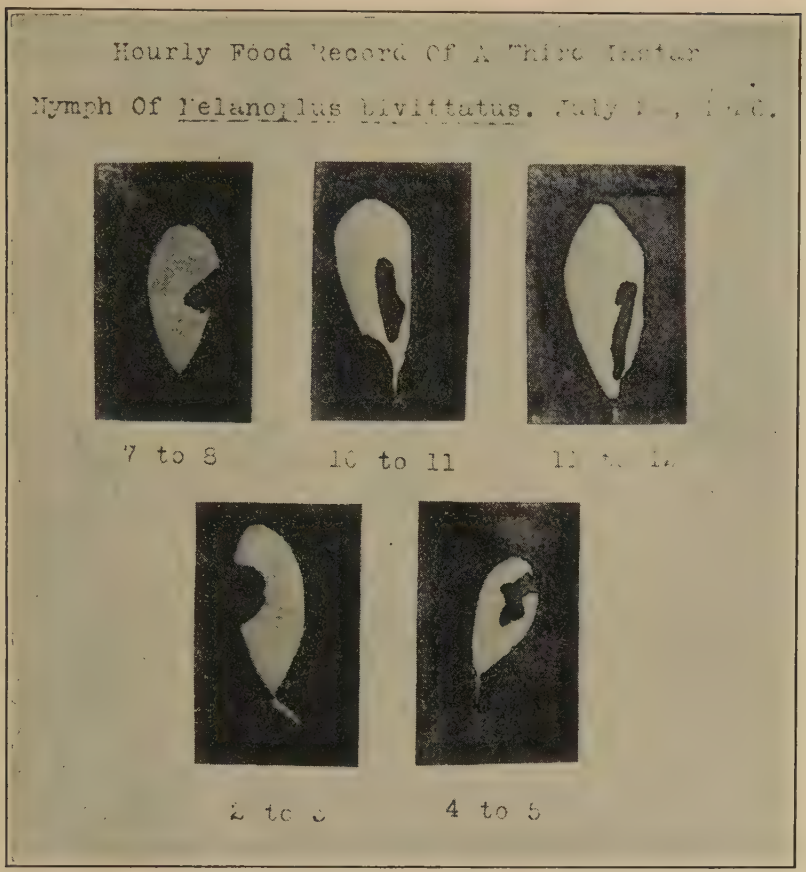

Fig. 3.—Photograph showing photo-print method of recording the amount of food eaten hourly by a grasshopper on alfalfa. (Slightly reduced.)

pers vary in the amount of food they eat when feeding on different plants.

The method has a distinct advantage in that large amounts of work can be done during the months when the insects are available and the data may be worked at another time. There is a disadvantage in the method in that it is subject to some experimental error. Plants growing under different moisture conditions will vary in the amount of water they contain in their tissues, also in the thickness of their leaves. This, of course, would cause some variation in determining the dry weight from figures obtained by the above method.

Most of the plants used in the experiments were obtained from plants grown under normal cultural practices. The alfalfa

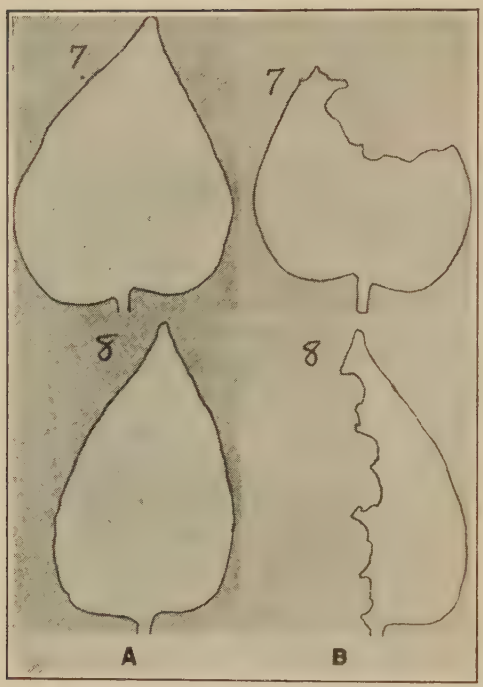

Fig. 4.—Photograph showing results of grasshopper feeding as recorded by photoprints. A, before feeding; B after feeding. (Slightly reduced.)

used was obtained, for the most part, from fields under normal irrigation conditions. All the grasshoppers used in the experiments were hatched from eggs collected in the field during early spring or from females kept in the laboratory. The conditions of insect growth were varied by the use of greenhouse, insectary and constant-temperature chambers.

Effects of Temperature on Activities

Grasshoppers belong to that group of animals that do not have a heat-regulating mechanism, therefore they must depend upon the temperature of their surroundings. The temperatures of their environment in which activity takes place are variable and may be subject to sudden changes. In studying the habits of grasshoppers it is quite important to know the temperatures in which they are active and function normally, also the optimum temperature.

Parker (54), working on *Camnula pellucida*, found that when the air temperature goes above 60 degrees F. some crawl from their hiding places and at 65 degrees F. nearly all will be in the open. After the air temperature extends above 68 degrees F. they begin to move about and enter upon the normal activities of the day. First and second instar nymphs have for their optimum a temperature range of 98 to 100 degrees F. As a rule, feeding stops at 68 degrees F. as the minimum. For the maximum, feeding sometimes continued in temperature cabinets until a temperature of 113 degrees F. was reached.

The writer, working with *Melanoplus bivittatus*, found this species reacted very similarly and within approximately the

Daily Food Record Second Instar Melanoplus bivittatus
Showing Hours of Feeding and Area of Leaf Surface
Consumed During the Day. May 26, 1927.
Food Plant - Lettuce

Mean hourly Temp.	65.5	73	79.5	83	83	84.5	86	86.5	85	81	77	74.5	Total Area Food Consumed In Square Inches
Temp. F.	61-70	70-76	76-83	83-83	83-83	83-86	86-86	86-87	87-83	83-79	79-75	75-74	
Hour	7-8	8-9	9-10	10-11	11-12	12-1	1-2	2-3	3-4	4-5	5-6	6-7	
Indiv. No.	Area Food Plant Consumed												
1			.035				.040			.040	.020	.010	.145
2					.010		.010	.015		.015	.010		.060
3	.030			.025	.010	.015	.005	.005		.015	.030		.135
4			.010	.010		.015	.020	.001			.010		.071
5	.015			.005			.040	.005	.010		.030		.105
6	.010		.007	.020		.020	.010	.010	.005		.020		.102
7	.020			.020		.015	.010	.040		.010	.020		.135
8	.002		.020	.015	.010	.010		.020	.010		.020		.107
9	.010	.005	.005	.015	.010	.020	.020	.015	.007	.005	.012		.124
10	.030				.030		.015	.005			.015		.105
11		.015	.005		.010	.025	.010	.005	.017			.005	.092
12	.020				.020			.030			.015	.005	.090
Total Area Eaten	.137	.020	.080	.110	.100	.120	.180	.151	.049	.085	.217	.020	1.271
No. Feeding	8	2	6	7	7	7	10	10	5	5	11	3	12
% Feeding	66	16	50	58	58	58	83	83	41	41	91	25	100

Fig. 5.—Photograph illustrating the method of recording the amount eaten by individual grasshoppers each hour.

same temperature limits as Parker found for *Camnula pellucida*. However, it was found that in a study of individuals of this species, in cages, that the range of activities was apparently slightly greater than that reported for *Camnula pellucida*.

Using the same type of apparatus described by Parker (54) the optimum temperature was found to be from 98 to 100 degrees F., the minimum effective to be from 65 to 68 degrees F. for normal activities, altho feeding on many occasions was observed to take place at much lower temperatures. Immature grasshoppers occasionally feed when the temperature does not exceed 58 degrees F. Adults were never observed feeding at temperatures below 60 degrees F. Table 1 includes records of grasshoppers feeding at low temperatures.

Temperatures above 104 to 105 degrees F. produced abnormal activities while temperatures from 110 to 115 degrees F. caused the grasshoppers to become very nervous. Increasing the temperature caused increased activity until the animals were overcome. On several occasions feeding was observed when the temperature was 112 and 115 degrees F. On one occasion an adult male was observed to feed upon a four o'clock leaf for a brief time when the temperature was 122 degrees F. Prolonged exposure at this temperature will cause death.

The above results show that *Melanoplus bivittatus* reacts normally between the temperatures of 68 to 100 degrees F. and that 98 to 100 degrees F. is the optimum.

Preliminary studies indicate that *Melanoplus bivittatus* can withstand higher temperatures than *M. Femur-rubrum*. Five experiments, the results of which are recorded in Table 2, all furnish evidence of this.

Individuals of the same species vary considerably in their ability to withstand heat. It is not uncommon for a few resistant individuals to be active when a vast majority of the individuals have succumbed.

Simple starvation tests indicate that temperature has an important bearing on the ability of grasshoppers to withstand starvation. Physiologically they appear to be so adjusted as to be able to survive long periods without food when the temperature is low, but very short periods when the temperature is high.

Table 1.—Minimum Temperatures at which Grasshoppers were Recorded Feeding.

Temp. range Fahr.	Hour a. m.	Number observed	Number feeding	Instar	Date
52—58	8— 9	8	2	1	5-18-26
54—58	8— 9	13	2	2	5-25-27
55—58	8— 9	8	0	3	6-3-26
55—58	8— 9	2	0	4	6-3-26
55—58	8— 9	7	1	1	6-3-26
55—58	8— 9	3	0	2	6-3-26
57—61	8— 9	4	2	3	5-27-26
57—61	8— 9	3	1	4	5-27-26
57—61	8— 9	5	4	1	5-27-26
57—61	8— 9	5	0	2	5-27-26
57—61	6— 7	11	4	3	6-2-27
58—60	9—10	4	2	1	5-28-26
58—60	9—10	5	0	2	5-28-26
58—60	9—10	4	1	3	5-28-26
58—60	9—10	3	2	4	5-28-26
59—61	8— 9	5	1	2	6-3-26
59—61	8— 9	5	1	3	6-3-26
59—61	8— 9	4	2	4	6-3-26
59—61	8— 9	10	0	1	6-3-26
61—63	8— 9	4	0	3	5-26-26
61—63	8— 9	3	1	4	5-26-26
61—63	8— 9	5	3	1	5-26-26
61—63	8— 9	5	1	2	5-26-26
53—62	8— 9	12	8	2	5-23-27
60—63	7— 8	9	6	3	6-1-27
60—63	7— 8	13	6	3	6-1-27
58—64	7— 8	9	2	4	6-17-27
58—64	7— 8	10	4	4	6-17-27
58—64	7— 8	11	7	4	6-17-27
58—64	7— 8	5	3	5	6-30-27
61—63	9—10	25	13	Adult F.	10-29-26
61—63	9—10	14	6	Adult M.	10-29-26

Table 2.—Preliminary Comparison of Effect of High Temperature on *Melanoplus bivittatus* and *Melanoplus femur-rubrum*.

Exp.	Date 1927	Species	Temp. Fahr.	Number minutes exposed	Percentage dead after 24 hours
1	9-12	*M. femur-rubrum*	130	40	65
	9-12	*M. bivittatus*	130	40	0
2	9-13	*M. femur-rubrum*	130—145	40	100
	9-13	*M. bivittatus*	130—145	40	66
3	9-13	*M. femur-rubrum*	140—150	35	100
	9-13	*M. bivittatus*	140—150	35	66
4	9-13	*M. femur-rubrum*	160	7	100
	9-13	*M. bivittatus*	160	7	50
5	9-13	*M. femur-rubrum*	140	?	62
	9-13	*M. bivittatus*	140	?	17
	9-13	*M. differentialis*	140	?	84

The grasshoppers were placed in cages as illustrated in Figure 1 and then placed in the temperature cabinet and allowed to remain for the length of time indicated. Therefore these figures do not represent the actual time the animals were exposed to the stated temperatures.

Montana entomologists (55) have shown that the amount of food grasshoppers eat depends upon the temperature. The writer's work discussed elsewhere in this paper corroborates this. Apparently more food is required to care for the increased metabolic activities under high temperature conditions. Bodine (6) has shown that there is a correlation between water content and temperature. He pointed out that in passing from low to high temperatures the water content of grasshoppers increases. Also that starvation reduces the water content. Thus it would seem logical that if these animals were exposed to high temperatures it would require more food to maintain the necessary water content for normal metabolic activities.

The summarized results of the starvation tests are as follows: When *M. femur-rubrum* and *M. differentialis* were exposed to a constant temperature of 95 degrees F. for 48 hours there was an average mortality of 70 percent, while the same species exposed to a temperature of 69 degrees F. were all alive at the end of 48 hours. At 55 degrees F. and after starvation for 120 hours all grasshoppers were alive. At 38 degrees F. 100 percent were alive after 192 hours, and 40 percent showed signs of life after 312 hours.

LIFE-HISTORY STUDIES AND TEMPERATURE

In order to obtain grasshoppers of given stages and of known ages, an extensive series of life-history studies was made. Detailed studies on the life histories of the following species were made for comparison: *M. bivittatus, M. differentialis, M. femur-rubrum* and *Chortophaga viridifaciatus*. Notes on the temperature and daily rate of development were recorded.

Temperature has a very important bearing on the rate of development. Parker (8) and Fry (29) have made and reported extensive studies on the effect of temperature on the rate of development. Since the writer's observations agree in essentials with the published work of these men, the details are omitted. Without doubt temperature is an important factor in development. As the Montana entomologists (55) have stated, it is possibly one of the factors affecting grasshopper outbreaks. The time of feeding, the amount of food eaten and the rate of development in the laboratory can be regulated by it.

By regulating the temperature, the life history from the hatched egg to the adult stage may be completed in less than 30 days, or may require more than 4 months. The period between moults may vary from 3 to 30 days depending on the temperature. On one occasion a newly hatched nymph kept at a relatively low temperature lived 108 days without moulting.

Grasshoppers moult from 5 to 7 times. The factor which causes this variation was not determined. In a series that developed in the greenhouse from March 5 to about June 10 under comparatively low temperatures practically all individuals moulted 6 or 7 times.

Another series developing from May 10 to about July 15 and subject to higher temperatures completed growth with but few exceptions in 5 moults. This would indicate that temperature is a factor. However, another series of *M. differentialis* growing under a constant temperature of 95 degrees F., all moulted 6 or 7 times. This would indicate that some other factor might be causing some of the variation. Indications are that the grasshoppers having the greater number of moults are the largest. This has always been the case with those studied by the writer.

Somes (74) states that there are 2 broods of *Chortophaga viridifaciatus* in Minnesota. Blatchley (1920) in his treatise on *Orthoptera* of N. E. North America, states that there is 1 generation in Indiana. Very careful rearings show that there is 1 generation in the vicinity of Fort Collins, Colorado. The adults are present from late April until fall. Egg deposition begins the latter part of May or early June and may continue for several weeks. Hatching may begin the latter part of June and continue for several weeks. Most of the nymphs begin hibernating in the third or fourth instar.

In the vicinity of Fort Collins eggs of *M. bivittatus* have been observed hatching as early as April 20. The majority of the eggs hatch during May and early June. Adults were found in the field on June 20 in 1926. Most of the nymphs mature dur-

ing July. Development takes place over a period of several weeks. Nymphs can often be found in the field from about April 20 to September 1.

OBSERVATIONS ON EGG DEPOSITION *Melanoplus bivittatus*

No extensive observations were made of the egg-laying habits. However, during the summer and fall months of 1925 and 1926 a series of observations were made on *M. bivittatus* in the vicinity of Fort Collins. Special emphasis was placed upon the egg-deposition period, number of eggs laid and the time and conditions required for deposition.

It was found that many individuals of this species are copulating freely from the first week to the middle of July. On July 13, 1925, a number of females were examined that contained well-developed eggs within the abdomen. By August 14 a large percentage of females had their abdomens distended with eggs. Egg deposition may take place from the middle of August until the middle of October. On October 17, 1926, females were observed laying during the middle of the day.

During the summer and fall months females were collected and caged in order that information might be obtained concerning the number of eggs deposited and the time required. During this same period females were dissected and counts made of the number of eggs in their ovaries.

From the egg counts made there seems to be a wide variation in the number of eggs in an egg pod. From a total of 42 pods examined the number of eggs per pod varied from 15 to 135 with an average of 59.8. In the counts made from 30 dissected gravid females the number of apparently fully developed eggs in the ovaries varied from 26 to 83 with an average of 68.

Observations were obtained from 24 individuals on the time required to deposit their eggs. The deposition period recorded was from the time the ovipositor began to be inserted in the ground until it was withdrawn. The soil temperature was recorded by placing a thermometer about 2 inches from the grasshopper and 1½ inches below the surface. All observations were made on caged grasshoppers. The minimum time required was 1 hour and 11 minutes, the maximum, 3 hours and 58 minutes, and the average was 2 hours and 3 minutes.

Only in one instance was egg laying observed when the temperature was below 70 degrees F. In that case the air temperature was 69 degrees F. On several occasions eggs were deposited when the soil temperature was 65 degrees F.

Eggs were deposited in a sandy soil with a moisture content as low as 9.77 percent and as high as 20 percent water.

Table 3.—Egg-laying Records—*Melanoplus bivittatus*, Fort Collins, Colorado, 1926.

Grasshopper No.	Date laid	Hour laying started	Hour finished	Time required for depositing eggs	Number Eggs in pod	Air temp.	Soil temp.	Soil moisture content
2	10-22	2:43 p. m.	4:59 p. m.	2 Hrs. 16 Min.	33	69 F.	65 F.	
7	10-26	11:50 a. m.	3:11 p. m.	3 Hrs. 21 Min.	65	77 F.	65 F.	10.01 percent
8	10-26	12:55 p. m.	3:11 p. m.	2 Hrs. 16 Min.	36	78 F.	69 F.	
11	10-25	2:12 p. m	5:45 p. m.	3 Hrs. 33 Min.	54	76 F.	69 F.	9.77 percent
13	10-26	12:00 noon	3:17 p. m.	3 Hrs. 17 Min.		77 F.	68 F.	
17	10-27	1:00 p. m.	3:51 p. m.	2 Hrs. 51 Min.		78 F.	65 F.	
18	10-26	1:00 p. m.	4:38 p. m.	3 Hrs. 38 Min.	135	78 F.	69 F.	
30	10-25	11:54 a. m.	3:30 p. m	3 Hrs. 36 Min.	80	77 F.	67 F.	13.16 percent
22	10-25	11:33 a. m.	3:17 p. m.	3 Hrs. 44 Min.	81	78 F.	67 F.	13.16 percent
32	10-25	10:00 a. m.	11:11 a. m.	1 Hr. 11 Min.	69	80 F.	68 F.	9.78 percent
40	10-25	11:20 a. m.	1:06 p. m.	1 Hr. 46 Min.	51	75 F.	65 F.	20.00 percent
41	10-25	2:22 p. m.	5:00 p. m.	2 Hrs. 38 Min.	45	76 F.	67 F.	13.57 percent
9	10-22	12:00 noon	2:55 p. m.	2 Hrs. 55 Min.	90	70 F.	66 F.	
15	10-25	2:12 p. m.	5:00 p. m.	2 Hrs. 48 Min.	73	75 F.	69 F.	10.01 percent
14	10-25	11:54 a. m.	3:52 p. m.	3 Hrs. 58 Min.	15	76 F.	68 F.	
27	11-4	11:45 a. m.	2:36 p. m.	2 Hrs. 51 Min.		72 F.	68 F.	
26	11-5	2:06 p. m.	4:00 p. m.	1 Hr. 54 Min.		72 F.	69 F.	
46	11-4	1:20 p. m.	3:54 p. m.	2 Hrs. 34 Min.		82 F.	68 F.	
47	11-3	1:50 p. m.	3:29 p. m.	1 Hr. 29 Min.	66	76 F.	69 F.	
19	11-4	2:00 p. m.	4:56 p. m.	2 Hrs. 56 Min.		75 F.	69 F.	
48	11-26	11:00 a. m.	12:55 p. m.	1 Hr. 55 Min.	52	76 F.	68 F.	
1	10-22	12:00 noon	3:58 p. m.	3 Hrs. 58 Min.		70 F.	66 F.	
10	10-21	1:05 p. m.	2:30 p. m.	1 Hr. 25 Min.		72 F.	66 F.	
12	10-22	12:00 ?	2:48 p. m.	2 Hrs. 48 Min.		70 F.		

Table 3 gives information concerning the egg deposition records.

Definite information on the number of egg pods a female of this species will lay was not obtained. However the writer obtained two pods of eggs from individuals and after death an examination showed them to contain well-developed eggs in their ovaries.

DAILY FEEDING ACTIVITIES

Investigators have made extensive studies to find the time of day that grasshoppers feed most on poisoned-bran mash. Practically all workers have concluded that temperature is a limiting factor but in general that the period of greatest feeding on poisoned-bran mash is during the morning hours after the temperature reaches 65 degrees F. or above, and continues until the temperature reaches 75 or 80 degrees F. This information has been obtained by a simple and effective method commonly termed the "pan method." Briefly, this method consists of placing fresh bait at hourly intervals on a series of pans, and then making counts each 10 minutes of the number of grasshoppers visiting and feeding at the pans. In literature there is but little information concerning the actual feeding activities of grasshoppers. Many farmers who poison and apparently a few scientists who have not worked with grasshoppers have come to believe that these insects feed heaviest during the morning hours when the temperature is between 75 and 80 degrees F.

The following experimental evidence will show why the "pan method" gives approximately a true measure to feeding on poisoned-bran mash, but does not show any relation to the feeding activities of a grasshopper during the entire day.

Temperatures recorded by the standard method employed by the weather bureau cannot be considered when reckoning with individual grasshoppers, since the temperature in the immediate proximity of the grasshopper must be used as a basis. Numerous observations have demonstrated that a variation of 70 to 80 degrees may be obtained at the same time within a given field. According to Hann's Handbook of Climatology, a difference as great as 128.30 degrees F. may exist, in high altitudes, between sun and shade temperature. Thus, within temperature ranges where activity is possible, grasshoppers have an opportunity to and do orient themselves so as to remain in or near their optimum by using grass, debris and other available materials. If such were not the case during an ordinary summer,

many grasshoppers in open fields would be destroyed from heat rigor.

Using an actual case recorded at Fort Collins, Colorado, June 30, 1926, the following temperature variations were recorded:

Hour	8	9	10	11	12	*1	2	3	4	5
Air Temperature	76	77.5	78	77	86	81	81	78	73	65
Temperature at soil surface in sun	95	100	114	103	107	102	92	89	76	64
Temperature at base of alfalfa in shade	62	66	73	69	78	73	70	70	67.5	64
Temperature 21 inches above ground in sun	78.5	80	81.5	77	87.5	77	75.5	74	70.5	63
Temperature 8 inches above ground in alfalfa shade	69	69	79	76	87.5	77	72.5	73	69.5	64

*After 1 p. m., sky hazy to cloudy.

If we should select from the above data the temperatures at the soil surface, and then allow the grasshoppers to remain at or below their optimum, and from this construct a curve, it would show, during the day, 2 peaks when grasshoppers are most likely to be found on and feeding at the ground. This curve would rise rapidly during the morning until at 9:30 a. m., then it would fall and remain low for a period until 1:30 or 2:00 p. m. At this time it would again rise rapidly and remain high until 5:00 p. m., and again fall. This curve is very similar to one that would be obtained from using the "pan method" and represents the periods during the day when the grasshoppers are in contact with and feeding upon the poisoned-bran mash which is scattered upon the ground. Yet it cannot be relied upon to represent the actual feeding operations of grasshoppers. The "pan method" will always yield the above-mentioned type of curve and grasshoppers will feed heaviest on poisoned-bran mash during the above periods for several reasons.

1. In early morning during the "warming up" period grasshoppers always collect in the open and in places where they can obtain the maximum warmth from the sun. Here they will remain and feed until the temperature passes their optimum. The pans afford an ideal place for this. This is also a period when they are in contact with the poisoned-bran mash.

2. As soon as the temperature passes the optimum the grasshoppers move and adjust themselves to a more suitable temperature in the vegetation but continue to feed.

3. During the afternoon, as the temperature falls, the areas shaded by vegetation cool, so that the grasshoppers react again and are found in more open places having a temperature

nearer their optimum. The pans again afford an ideal place. This accounts for the afternoon peak.

In a laboratory study of *M. bivittatus*, in all stages of its development and feeding on both alfalfa and lettuce, it was found that this grasshopper begins feeding as soon as the temperature reaches 65 to 68 degrees F. and continues to feed during the entire day, the greatest amount of feeding usually taking place during that portion of the day when the mean hourly temperature is highest. Normally, this occurs during the middle of the day; however there may be some variation to this. The above results are indicated by the percentage of animals feeding; the number of hours in which feeding occurred and the amount of food eaten. Details of the summarized individual experiments are given in Table 5.

The summarized results which represent the feeding of a total of 123 grasshoppers on lettuce over a period of 11 days and a total of 146 grasshoppers on alfalfa over a period of 13 days, afford additional evidence for the above statements. The day was divided into 3 equal parts of 4 hours each and the results are based on the averages for each of these periods. The maximum variation in the numbers feeding on alfalfa was 4.1 percent between any of the periods. For those feeding on lettuce, the maximum variation was 4.9 percent. The variation in the number of hourly periods in which feeding occurred and the amount eaten was somewhat greater. The latter variation can be very closely associated with the fluctuation in temperature, which is to be expected since the grasshoppers eat more at high than low temperatures. Table 4 gives the results.

Table 5.—Showing the Distribution of the Daily Feeding Activities of *Melanoplus bivittatus*.

	Morning period 7 a. m.-11 a. m.		Noon period 11 a. m.-3 p. m.		Afternoon period 3 p. m.-7 p. m.	
	Alfalfa*	Lettuce**	Alfalfa*	Lettuce**	Alfalfa*	Lettuce**
Percentage Feeding	69.8	86.9	73.9	91.8	72.6	91.8
Number hourly periods in which feeding occurred ..	154	208	166	280	178	237
Amount eaten— square inches ..	23.5	9.3	25.7	16.9	27.8	11.6
Mean hourly temperature	69	70.3	79.8	82.8	74.5	76

*Nymphs and adults. Data based on averages from feeding records taken on 13 different days, using 146 individuals.

**Nymphs. Data based on averages from feeding records taken on 11 different days, using 123 individuals.

Table 5.—Daily Food Record *Melanoplus bivittatus* Based on Hourly Feeding Records—12-hour Day, Fort Collins, Colorado.
Food plant—Lettuce

Exp.	Date	Morning period				Noon period				Afternoon period				Number of individuals	Range of temp. Fahr. from 7 a. m. to 7 p. m.	
		Percentage feeding	Number periods feeding occurred	Amount food consumed	Mean hourly temp.	Percentage feeding	Number periods feeding occurred	Amount food consumed	Mean hourly temp.	Percentage feeding	Number periods feeding occurred	Amount food consumed	Mean hourly temp.		Max.	Min.
	1926															
								First instar								
200	5-16	84	13	.116	70.5	69	13	.240	84.3	92	24	.353	78.2	13	87	55
300	5-17	100	33	.484	76	100	36	.443	84.8	100	28	.329	78.8	14	89	60
								Second instar								
300	5-23	83	19	.407	63.2	100	32	.746	81	100	22	.426	73.4	12	85	50
200	5-25	69	12	.260	68.8	100	32	.541	86.6	92	22	.284	78.4	13	89	51
300	5-25	91	23	.349	74.6	100	34	.551	85	100	24	.371	79.6	12	87	61
								Third instar								
200	6-1	84	29	1.208	72.6	100	34	2.017	85.2	100	29	1.461	74.4	13	87	57
300	6-2	90	19	.770	71.4	100	28	1.387	80	100	24	1.120	72	11	89	57
								Fourth instar								
200	6-17	90	17	1.755	69.6	80	22	2.640	80.4	70	15	1.710	76.6	10	83	58
300	6-17	100	24	1.635	69.6	72	22	2.510	80.4	72	22	1.935	76.6	11	83	58
								Fifth instar								
200	6-30	75	13	1.445	68.6	87	13	3.160	81.6	87	15	1.870	75.4	8	85	58
300	6-30	83	6	.970	68.6	100	14	2.750	81.6	83	12	1.830	75.4	6	85	58

Table 5.—Continued.—Daily Food Record *Melanoplus bivittatus* Based on Hourly Feeding Records—12-hour Day, Fort Collins, Colorado.
Food plant—Alfalfa

Exp.	Date	Morning period				Noon period				Afternoon period				Number of individuals	Range of temp. Fahr. from 7 a. m. to 7 p. m.	
		Percentage feeding	Number periods feeding occurred	Amount food consumed	Mean hourly temp.	Percentage feeding	Number periods feeding occurred	Amount food consumed	Mean hourly temp.	Percentage feeding	Number periods feeding occurred	Amount food consumed	Mean hourly temp.		Max.	Min.
								First instar								
	1926															
11-A	5-18	88	11	.051	71.3	66	6	.048	79.7	77	8	.070	76.2	9	87	67
								Second instar								
	1927															
100	5-25	100	11	.207	74.6	100	15	.199	85	88	12	.153	79.6	9	87	61
	1926															
26-A	7-23	75	9	.290	64.3	62	13	.410	76.4	27	6	.160	71	8	80	58
								Third instar								
	1927															
100	6-1	100	21	.356	72.6	100	15	.245	85.2	100	12	.313	74.4	9	87	60
	1926															
14-A	6-2	50	7	.259	67.4	75	8	.161	77.7	75	7	.223	77.1	8	80	58
17-A	6-2	80	14	.443	71	60	8	.374	86	80	12	.604	78	10	90	58
21-A	7-20	80	11	.530	67	50	7	.300	77.2	100	13	.600	73.6	10	84.5	57.5
								Fourth instar								
	1927															
100	6-17	66	9	.315	69.6	77	9	.510	80.4	77	11	.670	76.6	9	83	58
								Fifth instar								
	1927															
100	6-30	100	8	.520	68.6	60	5	.234	81.6	60	5	.770	75.4	5	85	58
	1926															
22-A	7-20	61	15	6.160	67	77	23	6.050	77.2	77	23	5.970	73.6	18	84	57
25-A	7-23	61	13	5.020	69.6	72	24	4.980	77.5	77	23	5.030	70.8	18	80	62
								Adult males								
	1926															
24-A	7-23	43	11	3.500	67.3	75	16	4.440	76.6	81	22	6.030	69.6	16	80	60
23	7-20	58	14	5.860	67	76	17	7.810	77.2	82	24	7.270	73.6	17	84	57

The above considerations are based entirely upon laboratory observations, but it appears logical that the same results should be obtained under field conditions as long as the temperature is sufficiently high to be within the range of activity and since the grasshoppers react to temperature so as to maintain themselves in their optimum or as near it as possible. To make records of these data in the field, of course, would be difficult.

AMOUNT OF FOOD CONSUMED DAILY

A knowledge of the amount of food consumed daily for a given infestation of grasshoppers is of value to the field entomologist in making estimates of crop losses. Especially is this true when it is necessary to impress the value of control upon farmers.

Morril (45), working in Arizona, reported that grasshoppers eat approximately 1 gram of green alfalfa each 24 hours. This is somewhat more than the writer found for grasshoppers in Colorado. However, the higher temperatures, with warmer mornings and evenings of Arizona should permit much more feeding.

The writer, in experiments conducted as described by Morril, found that with a mean hourly temperature of 80 degrees F., adult females of *M. bivittatus* averaged .527 grams each over a period of 12 hours. After the amount which was cut and fell to the ground as waste was substracted, each grasshopper averaged .439 grams for a 12-hour day. The conditions of growth of alfalfa such as amount of shade, sunshine and irrigation will cause a variation, but alfalfa grown under normal irrigation averages about 8 square inches to 1 gram. According to this, each grasshopper ate an average of 3.512 square inches of alfalfa per day. This amount was within the limits of variation of gravid females as determined by measurements of areas eaten.

The writer found in his investigations that grasshoppers require greater quantities of one kind of food plant than another, and since the values of crops vary, it is also important to know the quantities that can be destroyed of each type of crop in order that accurate estimates of losses may be made. This phase has been kept in mind, and accordingly the writer has used plants in his experiments and expressed the results in terms of square inches. If it is desired these figures can later be expressed in weight.

It is difficult to state accurately the amount of food a grasshopper, or a given number of grasshoppers, will eat in a given day. The temperature, the kind of food, the age of the grasshop-

per, the sex, the stage of development, length of day and various other factors cause variation. The following statement will illustrate the extreme amount of variations. *M. bivittatus* feeding on lettuce may have a variation of from .02 square inches for newly hatched nymphs to 7.52 square inches for an adult female. Under constant temperature of 95 degrees and light, thus lengthening the feeding day to 24 hours, a female may eat as much as 11.30 square inches.

The following figures give the range for *M. bivittatus* feeding on alfalfa and lettuce during a 12-hour day and in temperatures ranging from 68 to 95 degrees F.

Instar	Alfalfa Square inches	Number of individuals	Lettuce Square inches	Number of individuals
1	.005- .035	301	.02- .14	56
2	.02 - .08	104	.04- .24	53
3	.03 - .16	76	.10- .692	66
4	.035- .360	43	.18-1.57	55
5	.10 - .25	35	.48-3.90	22
6	.30 -1.76	18	.68-8.80	36
7	-		.68-7.90	11
Adult females	.50 -4.32	52	2.00-7.52	21
Audlt males	.40 -2.64	47	1.50-5.90	14

There is a wide daily variation in the amount of food eaten by individuals of the same brood hatched from the same batch of eggs and kept apparently under the same conditions. In the case of adult *M. bivittatus* feeding on lettuce, the variation may be almost 4 square inches. Specific examples of this may be seen by examining Table 4. Not only do individuals of the same brood vary in the amount they eat per day but the same individuals under constant temperatures and apparently indentical conditions vary from day to day.

As stated before, accurate averages are hard to make due to many variable factors and especially to the fact that in a climate like Colorado the temperature varies greatly within a day and from day to day. The following figures give the average amount of leaf surface consumed in square inches for *M. bivittatus* during a 12-hour day under temperature conditions ranging within feeding activities, 65 to 95 degrees F.

Instar	Alfalfa square inches	Number grasshoppers studied	Lettuce square inches	Number grasshoppers studied
1	.012	301	.058	56
2	.030	104	.116	53
3	.078	76	.284	66
4	.107	43	.549	55
5	.557	35	1.622	22
6	1.100	18	2.678	36
7			2.435	11
Adult males	.950	52	2.666	21
Adult females	1.875	47	5.950	14

The above averages must be considered as being conservative. In the open a grasshopper probably gets considerably more exercise than one caged and it would appear logical that under such conditions it would need more food to maintain itself. Depending on the season, but normally, under field conditions it is possible for a grasshopper to maintain a higher mean hourly temperature than these records, and on many occasions to feed over longer periods.

A study of the average amount of food consumed by developing grasshoppers is very interesting. It clearly shows one of the advantages of poisoning while the grasshoppers are young. With each moult a grasshopper almost doubles the amount of food eaten daily. Adult females eat almost 100 times more food

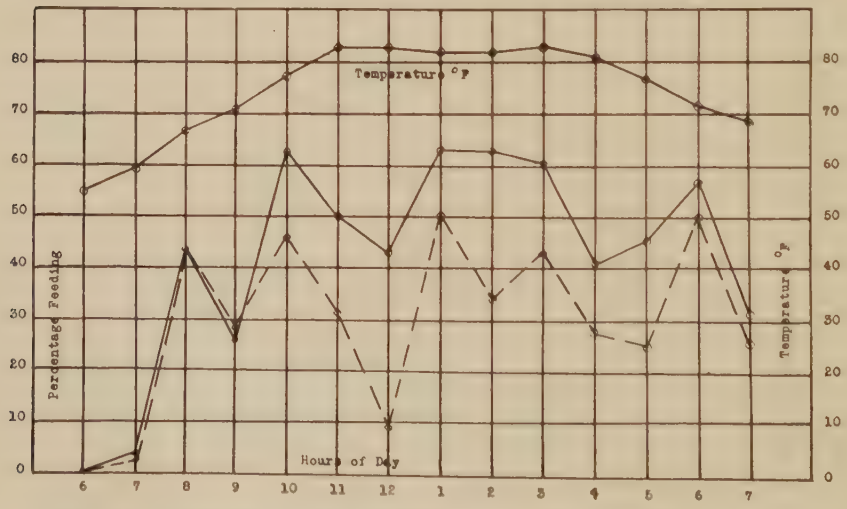

Fig. 6.—A comparison of the difference in the rate of feeding of nymphs of *Melanoplus bivittatus* on different plants. Upper line indicates the mean hourly temperature. Solid line represents feeding on lettuce based on 60 individuals. Broken line represents feeding on alfalfa based on 32 individuals.

per day than first instar nymphs. Aside from the losses incurred during the process of development, it is very evident that it required from 70 to 80 times more food per day to maintain an equal number of adult grasshoppers than first instar nymphs. Even within the same instar the amount eaten increases enormously as the grasshoppers grow older. The following example will illustrate:

Fourteen 1-day-old *Chortophaga viridifaciatus* ate an average of .082 square inches of lettuce each in 24 hours under a constant temperature of 95 degrees F. The maximum amount eaten by a single individual was .120 square inches, and the minimum amount was .060 square inches. At the age of 4 days these same grasshoppers under apparently the same conditions ate an average of .145 square inches each, with a maximum of .200 square inches and a minimum of .092 square inches.

Table 6.—Notes on the Amount of Food Consumed During a Day by Grasshoppers.

Food plant—Alfalfa

Exp.	Date 1927	Amount of food Consumed Max.	Min.	Ave.	Number grass-hoppers	Temp. Fahr. Max.	Min.	Hourly mean	Hours of feeding a.m.	p.m.	Species
					First instar						
	5-4	.011	.001	.004	15				8	8	M.b.*
	5-5	.025	.001	.010	31				8	8	"
	5-6	.022	.001	.006	21				8	8	"
	5-6			.014	45				8	8	"
	5-7	.019	.001	.006	17				8	8	"
7a	5-18	.017	.003	.011	10	78	62	68.7	8	7	"
7b	7-3	.032	.010	.021	15	83	66	74.9	8	7	"
10	5-18	.014	.003	.008	7	64.5	48.5	57.5	6	6	"
11	5-18	.035	.001	.018	9	90	64	74.5	6	6	"
12	5-21	.017	.014	.015	2	90	64	77.5	5	7	"
13	5-21	.012	.002	.005	3	75.5	57	67.7	5	7	"
6	5-27	.020	.013	.015	3	80	61	70.5	7	7	"
6	5-27	.010	.001	.004	5	71	56	62.7	7	7	"
5	5-28	.005	.005	.005	1	65.5	53.5	59.3	7	7	"
3	5-29	.011	.008	.010	3	90	66	79.7	7	7	"
3	5-29	.008	.003	.005	4	68	55	63.4	7	7	"
15	6-2	.032	.007	.015	5	80	55	70.8	5	7	"
19	6-2	.032	.003	.014	8	80	58	76	5	7	"
2	6-5	.012	.004	.009	3	78	70	74.3	7	7	"
2	6-5	.009	.004	.007	4	73	60	66	7	7	"
100—10	5-11	.014	.002	.008	9	86	55	76.5	7	7	"
100—10	5-17	.035	.020	.027	9	89	60	79.2	7	7	"
100—10	5-18	.020	.005	.013	7	86	55	75	7	7	"
16—21	4-23	.025	.010	.016	7	84	61	76	7	7	M.f-r

*M. b.—*Melanoplus bivittatus*
M. f-r—*Melanoplus femur-rubrum*

Table 6.—Continued.—Notes on the Amount of Food Consumed During a Day by Grasshoppers.

Food plant—Alfalfa

Exp.	Date 1927	Amount of food Consumed Max.	Min.	Ave.	Number grass-hoppers	Temp. Fahr. Max.	Min.	Hourly mean	Hours of feeding a.m.	p.m.	Species
					Second instar						
	5-4	.035	.002	.013	15				8	8	M.b
	5-5	.040	.001	.019	12				8	8	"
	5-6	.030	.001	.013	12				8	8	"
	5-7	.020	.001	.009	7				8	8	"
12	5-21	.032	.032	.032	1	90	64	77.5	7	7	"
6	5-27	.042	.002	.029	5	80	61	70.5	7	7	"
6	5-27	.011	.003	.006	4	71	56	62.7	7	7	"
5	5-28	.009	.002	.005	2	65.5	53.5	59.3	7	7	"
5	5-28	.028	.011	.017	3	84	64	73.8	7	7	"
3	5-29	.019	.018	.018	2	90	66	79.7	7	7	"
	6-2	.015	.015	.015	1				7	7	"
15	6-2	.048	.006	.027	2	80	55	70.8	5	7	"
19	6-2	.120	.017	.066	3	90	58	76	5	7	"
2	6-5	.040	.006	.018	3	73	60	66	7	7	"
2	6-5	.035	.018	.026	2	78	70	74.3	7	7	"
100—10	5-25	.080	.045	.062	9	87	61	78.9	7	7	"
A-E	5-17	.085	.050	.062	5	89	60	79.9	7	7	"
A-E	5-18	.045	.027	.038	5	86	55	75.7	7	7	"
A-E	5-19	.070	.045	.056	4	84	56	75.6	7	7	"
A-E	5-20	.055	.030	.045	4	86	58	77.8	7	7	"
A-E	5-23	.070	.030	.055	3	82	51	70.2	7	7	"
16—21	5-5	.050	.005	.027	5	85	62	76.1	7	7	M.f-r
16—21	5-6	.060	.005	.027	6	85	60	77.2	7	7	"
16—21	5-10	.050	.025	.040	4	91	69	79.5	7	7	"
16—21	5-11	.065	.025	.045	3	92	51	77			"
					Third instar						
12	5-21	.043	.011	.027	2	90	64	77.5	5	7	M.b.
6	5-27	.027	.015	.021	3	71	56	62.7	7	7	"
6	5-27	.065	.030	.053	3	80	61	70.6	7	7	"
5	5-28	.062	.028	.041	3	84	64	73.8	7	7	"
3	5-29	.031	.030	.030	2	68	55	63.4	7	7	"
3	5-29	.075	.032	.057	3	90	66	79.7	7	7	"
14	6-2	.147	.005	.077	6	80	55	70.8	5	7	"
17	6-2	.170	.025	.077	5	90	58	76	5	7	"
2	6-5	.082	.010	.040	4	78	70	74.3	7	7	"
2	6-5	.075	.025	.050	2	73	60	66	7	7	"
21	7-20	.250	.020	.149	10	84	57	72	5	8	"
26	7-23	.170	.050	.107	8	80	58	69.6	5	8	"
100—14	6-1	.138	.054	.101	9	87	57	79	6	7	"
A-E	5-26	.160	.100	.131	4	89	68	80	7	7	"
A-E	5-31	.120	.090	.105	4				7	7	"
A-E	6-1	.080	.057	.068	4	90	57	75	7	7	"
A-E	6-2	.075	.030	.046	3	89	58	74	7	7	"
1—4	4-25	.240	.240	.240	1	86	56	79	7	7	"
16—21	5-10	.080		.080	1	91	69	79.5	7	7	M.f.r.
16—21	5-11	.050	.030	.040	2	92	51	77	7	7	"
16—21	5-11	.095	.030	.068	4	89	60	79.9	7	7	"
16—21	5-17	.095	.030	.068	4	89	60	79.9	7	7	"
16—21	5-18	.065	.038	.049	4	86	55	75.7	7	7	"
16—21	5-19	.070	.040	.058	3	84	56	75.6	7	7	"
16—21	5-20	.060	.060	.060	2	86	58	77.8	7	7	"

Table 6.—Continued.—Notes on the Amount of Food Consumed During a Day by Grasshoppers.

Food plant—Alfalfa

Exp.	Date 1927	Amount of food Consumed Max.	Min.	Ave.	Number grass-hoppers	Temp. Fahr. Max.	Min.	Hourly mean	Hours of feeding a.m.	p.m.	Species
16—21	5-23	.085	.060	.068	3	82	51	70.2	7	7	"
16—21	5-26	.060		.060	1	89	68	80	7	7	"
16—21	6-1	.110		.110	1	90	57	75	7	7	"
16—21	6-2	.090		.090	1	89	58	74	7	7	"
				Fourth instar							
6	5-27	.115	.080	.097	2	80	61	70.5	7	7	M.b.
6	5-27	.073	.051	.061	2	71	56	62.7	7	7	"
5	5-28	.081	.034	.050	3	84	64	73.8	7	7	"
5	5-28	.035	.032	.033	2	65.5	53.5	59.3	7	7	"
3	5-29	.170	.040	.099	3	90	66	79.7	7	7	"
3	5-29	.055	.035	.042	2	68	55	63.4	7	7	"
14	6-2	.112	.060	.086	2	80	55	70.8	5	7	"
17	6-2	.612	.004	.209	5	90	58	76	5	7	"
2	6-5	.110	.030	.078	4	78	70	74.3	7	7	"
2	6-5	.130	.047	.084	3	73	60	66	7	7	"
100—14	6-17	.290	.040	.161	9	83	57	72	6	8	"
A-E	6-7	.230	.110	.171	4	91	70	82	7	7	"
1— 4	5-25	.025	.200	.220	2	86	56	79	7	7	"
16—21	5-19	.080		.080	1	84	56	75.6	7	7	M.f.r.
16—21	5-19	.120	.100	.110	2	86	56	77.8	7	7	"
16—21	5-23	.100		.100	1	82	51	70.2	7	7	"
16—21	5-26	.090	.070	.080	2	89	68	80	7	7	"
16—21	6-1	.100	.075	.090	3	90	57	75	7	7	"
16—21	6-2	.075	.035	.053	3	89	58	74	7	7	"
				Fifth instar							
—25	7-23	1.68	.430	.83	18	80	58	69.6	5	8	M.b.
100—14	6-24	1.230	.220	.700	9	93	65	83	7	7	"
100—14	6-30	.470	.100	.233	4	85	58	73	7	7	"
A-E	6-24	.620	.210	.425	4	92	65	84	7	7	"
16—21	6-1	.245		.245	1	90	57	75	7	7	M.f.r.
16—21	6-2	.200		.200	1	89	58	74	7	7	"
				Sixth instar							
22	7-20	1.76	.300	1.10	18	84	57	72	5	8	M.b.
				Adult females							
24		2.64	2.50	2.57	2	80	58	69.6	6	8	M.b.
28	10-22	4.32	.08	2.12	20	78	64	69.4	8	5	"
37	10-29	1.13	.04	.354	25	66	48	61.7	8	5	"
	11-4	4.16	.15	1.63	27				8	5	"
				Adult males							
23	7-20	2.30	.46	1.23	17	84	57	72	6	8	M.b.
24	7-23	2.64	.15	.87	16	80	58	69.6	6	8	"
27	10-22	1.51	.01	.75	19	78	64	69.4	8	5	"
38	10-29	.47	.01	.174	14	66	48	61.7	8	5	"

Table 6.—Continued.—Notes on the Amount of Food Consumed During a Day by Grasshoppers.

Food plant—Lettuce

Exp.	Date 1927	Amount of food Consumed Max.	Min.	Ave.	Number grass-hoppers	Temp. Fahr. Max.	Min.	Hourly mean	Hours of feeding a.m.	p.m.	Species
					First instar						
1—4	3-30	.037		.037	1	81	65	73	7	7	M.b.
1—4	3-31	.039		.039	1	81	68	74	7	7	"
1—4	4-4	.047		.047	1	81	49	70	7	7	"
1—4	4-7	.025		.025	1	84	71	76	7	7	"
200—14	5-11	.080	.020	.043	14	86	55	76.4	7	7	"
200—14	5-13	.115	.040	.070	14	92	66	79.4	7	7	"
300—14	5-17	.140	.060	.088	14	89	55	79.2	6	7	"
A—200	5-6	.082		.082	5	91	69	79.5	7	7	"
A—200	5-10	.097		.097	5	91	69	79.5	7	7	M.b.
5—14	4-23	.050	.015	.038	6	84	61	76	7	7	M.f.r.
					Second instar						
1—4	3-29	.080	.065	.072	2	74	45	70	7	7	M.b.
1—4	3-30	.142	.105	.123	2	81	65	73	7	7	"
1—4	3-31	.100	.088	.094	2	81	68	74	7	7	"
1—4	4-9	.145		.145	1	81	65	74	7	7	"
1—4	4-12	.180		.180	1	80	65	73	7	7	"
1—4	4-13	.165		.165	1	83	65	73	7	7	"
1—4	4-14	.135		.135	1	77	67	71	7	7	"
1—4	4-4	.020		.020	1	81	49	70	7	7	"
1—4	4-11	.050		.050	1	78	54	70	7	7	"
F-M	5-18	.230	.115	.171	7	86	55	75.7	7	7	"
F-M	5-20	.180	.140	.151	6	86	58	77.8	7	7	"
F-M	5-23	.125	.095	.108	4	82	51	70.2	7	7	"
300—14	5-23	.187	.055	.130	12	85	50	71.4	7	7	"
300—14	5-25	.145	.060	.105	12	87	61	78.9	7	7	"
200—14	5-25	.125	.042	.082	13	89	51	75.3	7	7	"
5—14	5-6	.220	.100	.156	5	85	60	77.2	7	7	M.f.r.
5—14	5-5	.200	.090	.150	4	85	62	76.1	7	7	"
5—14	5-10	.205	.145	.170	3	91	69	79.5	7	7	"
5—14	5-11	.240	.200	.220	2	92	51	77	7	7	"
					Third instar						
1—4	3-30	.100		.100	1	81	65	73	7	7	M.b.
1—4	3-31	.165		.165	1	81	68	74	7	7	"
1—4	4-4	.265	.080	.172	2	81	49	70	7	7	"
1—4	4-7	.420	.285	.353	3	84	71	76	7	7	"
1—4	4-9	.260	.172	.216	2	81	65	74	7	7	"
1—4	4-11	.167	.152	.159	2	78	54	70	7	7	"
1—4	4-12	.155		.155	1	80	65	73	7	7	"
1—4	4-13	.097		.097	1	83	65	73	7	7	"
1—4	4-14	.185		.185	1	77	67	73	7	7	"
1—4	4-18	.350		.350	1	85	73	81	7	7	"
1—4	4-19	.250		.250	1	76	72	73	7	7	"
1—4	4-20	.540		.540	1	83	70	77	7	7	"
1—4	4-21	.610		.610	1	88	69	78	7	7	"
1—4	4-22	.530	.235	.382	2	88	70	79	7	7	"
1—4	4-23	.440	.290	.365	2	84	61	76	7	7	"
1—4A	4-26	.430		.430	1	93	68	84	7	7	"
1—4A	4-27	.090		.090	1	87	62	78	7	7	"
F-M	5-26	.480	.180	.331	7	89	68	80	7	7	"

Table 6.—Continued.—Notes on the Amount of Food Consumed During a Day by Grasshoppers.

Food plant—Lettuce

Exp.	Date 1927	Amount of food Consumed Max.	Min.	Ave.	Number grass-hoppers	Temp. Fahr. Max.	Min.	Hourly mean	Hours of feeding a.m.	p.m.	Species
F-M	6-1	.440	.200	.299	6	90	57	75	7	7	"
F-M	6-2	.260	.155	.212	5	89	58	74	7	7	"
300—14	6-2	.427	.175	.293	11	89	57	72	7	7	"
200—14	6-1	.692	.044	.337	13	87	57	79	6	7	"
5—14	5-10	.310	.290	.301	3	91	69	79.5	7	7	M.f.r.
5—14	5-11	.320	.280	.300	2	92	51	77	7	7	"
5—14	5-18	.450	.220	.350	3	86	55	75.5	7	7	"
5—14	5-20	.315	.270	.292	2	86	58	77.8	7	7	"
				Fourth instar							
1—4	4-11	.100		.100	1	78	54	70	7	7	M.b.
1—4	4-12	.300		.300	1	80	65	73	7	7	"
1—4	4-13	.280		.280	1	83	65	73	7	7	"
1—4	4-14	.440		.440	1	77	67	73	7	7	"
1—4	4-18	.720	.540	.653	3	85	73	81	7	7	"
1—4	4-19	.530	.520	.525	3	76	72	73	7	7	"
1—4	4-20	.800	.570	.685	2	83	70	77	7	7	"
1—4	4-21	.850	.660	.755	2	88	69	78	7	7	"
1—4	4-22	.820	.820	.820	2	88	70	79	7	7	"
1—4	4-23	.330	.280	.305	2	84	61	76	7	7	"
1—4	4-24	.430		.430	1	93	68	84	7	7	"
1—4	4-28	.500		.500	1	90	65	78	7	7	"
1—4A	5-5	.750	.500	.625	2	85	62	76.1	7	7	"
1—4A	5-6	.810	.680	.745	2	85	60	77.2	7	7	"
11	6-1	.460		.460	1	90	57	75	7	7	"
11	6-2	.310		.310	1	89	58	74	7	7	"
F-M	6-7	.770	.460	.560	6	91	70	82	7	7	"
300—14	6-17	.930	.010	.550	11	83	56	72	6	8	"
200—14	6-17	1.510	.100	.610	10	83	56	72	6	8	"
1—3	6-24	1.570	1.090	1.330	2	92	65	84	7	7	"
5—14	5-18	.490		.490	1	86	55	75.7	7	7	M.f.r.
5—14	5-20	.720	.300	.473	3	86	58	77.8	7	7	"
5—14	5-23	.620	.210	.405	4	82	51	70.2	7	7	"
5—14	5-26	1.000	.380	.666	6	89	68	80	7	7	"
				Fifth instar							
1—4	4-21	.910		.910	1	86	69	78	7	7	M.b.
1—4	4-22	1.100		1.100	1	88	70	79	7	7	"
1—4	4-23	.900		.900	1	84	61	76	7	7	"
1—4	4-26	1.520	.900	1.210	2	93	68	84	7	7	"
1—4	4-27	1.260	.700	1.025	2	87	62	78	7	7	"
1—4	4-28	1.390	1.050	1.220	2	90	65	78	7	7	"
1—4A	5-5	.520	.480	.500	2	85	62	76.1	7	7	"
1—4A	5-6	1.080	.640	.860	2	85	60	77.2	7	7	"
1—4A	5-11	1.780		1.780	1	92	51	77	7	7	"
1—4A	5-12	2.480		2.480	1	86	69	78.1	7	7	"
1—4A	5-13	2.660		2.660	1	92	66	79.1	7	7	"
1—4A	5-16	2.460		2.460	1	87	59	78.3	7	7	"
1—4A	5-17	3.150		3.150	1	89	60	79.2	7	7	"
1—4A	5-18	2.420		2.420	1	86	55	75	7	7	"
1—4A	5-19	1.800		1.800	1	83	58	74.6	7	7	"
1—4A	5-20	1.500		1.500	1	86	58	77.8	7	7	"
1—4A	5-23				1	85	50	71.4	7	7	"

Table 6.—Continued.—Notes on the Amount of Food Consumed During a Day by Grasshoppers.

Food plant—Lettuce

Exp.	Date 1927	Amount of food Consumed Max.	Min.	Ave.	Number grass-hoppers	Temp. Fahr. Max.	Min.	Hourly mean	Hours of feeding a.m.	p.m.	Species
				Sixth instar							
1—4A	5-6	1.100		1.100	1	85	60	77.2	7	7	M.b.
1—4A	5-9	2.400		2.400	1	96	62	78.8	7	7	"
1—4A	5-10	2.330		2.330	1	91	69	79.5	7	7	"
1—4A	5-11	2.460	1.500	2.130	2	92	51	77	7	7	"
1—4A	5-12	2.670	1.520	2.010	3	86	69	78.1	7	7	"
1—4A	5-13	3.720	2.130	2.763	3	92	65	79.1	7	7	"
1—4A	5-16	1.840	1.140	1.593	3	87	59	78.3	7	7	"
1—4A	5-17	3.350	2.520	3.006	3	89	60	79.2	7	7	"
1—4A	5-18	2.560	.680	1.680	3	86	55	75	7	7	"
1—4A	5-19	2.750	1.850	2.300	2	83	56	74.6	7	7	"
1—4A	5-20	2.200	1.600	1.900	2	86	58	77.8	7	7	"
1—4A	5-23	.680	.100	.390	2				7	7	"
1—4A	5-26	3.800		3.800	1	88	68	80.3	7	7	"
4	5-31	2.700		2.700	1	79	54	70	7	8	"
4	6-1	3.800		3.800	1	87	60	76	7	8	"
4	6-2	3.260		3.260	1	89	58	74	7	8	"
4	6-7	3.900		3.900	1	88	72		7	8	"
				Seventh instar							
1—4A	5-23	.960		.960	1						M.b.
1—4A	5-26	1.900	1.770	1.835	2	88	68	80.3	7	8	"
1—4	5-31	2.700	1.460	2.080	2	79	54	70	7	8	"
1—4	6-1	2.440	2.400	2.420	2	87	60	76	7	8	"
1—4	6-2	2.360	.340	1.350	2	89	58	74	7	8	"
1—4	6-7	3.900		3.900	1	88	70	81	7	8	"
4A	6-24	4.500		4.500	1	93	65	83	7	8	"
				Last instar (*Chortophago virid*)							
	4-8	1.470		1.470	1	83	65	74	7	8	
	4-11	.860		.860	1	78	54	70	7	8	
	4-12	1.600		1.600	1	80	65	73	7	8	
	4-13	1.280		1.280	1				7	8	
	4-14	1.590		1.590	1				7	8	
				Adult females (*Chortophago virid*)							
	4-22	2.450		2.450	1	88	70	79	7	8	
	4-23	2.850		2.850	1	84	61	76	7	8	
	4-26	2.120		2.120	1	93	68	84	7	8	
	4-27	2.940		2.940	1	87	62	78	7	8	
	4-28	2.370	.560	1.417	4	90	65	78	7	8	
	5-5	1.940	1.520	1.705	4	85	62	76.1	7	8	
				Adult males (*Chortophago virid*)							
	1-28	.960	.320	.688	10	90	65	78	7	8	
	5-5	.830	.380	.643	9	85	62	76.1	7	8	

Table 6.—Continued.—Notes on the Amount of Food Consumed During a Day by Grasshoppers.

Food plant—Lettuce

Exp.	Date 1927	Amount of food Consumed Max.	Min.	Ave.	Number grass-hoppers	Temp. Fahr. Max.	Min.	Hourly mean	Hours of feeding a.m.	p.m.
				Adult females—*M. bivittatus*						
1—4	6-17	6.680	6.120	6.400	2				7 - 8	
1—4	6-23	4.820	4.760	4.790	2				7 - 8	
1—4	6-24	7.520	7.000	7.260	2	93	65	83	7 - 8	
1—4A	6-30	7.010	4.800	5.843	3	85	58	73	7 - 8	
1—4A	7-2	6.000	3.900	5.266	3	89	58	74	7 - 8	
300—14	7-15	6.390	5.900	6.145	2	85	55	73	7 - 8	
				Adult males—*M. bivittatus*						
1—4	5-31	.820		.820	1	79	54	70	7 - 8	
1—4	6-1	2.750		2.750	1	87	60	76	7 - 8	
1—4	6-2	2.740		2.740	1	89	58	74	7 - 8	
1—4	6-7	3.700		3.700	1	88	70	81	7 - 8	
1—4	6-17	2.420	1.130	1.775	2	83	56	72	7 - 8	
1—4	6-23	5.110	2.000	3.555	2				7 - 8	
1—4	6-24	4.610	1.840	3.225	2	93	65	83	7 - 8	
1—4	6-30	2.350	1.210	1.780	2	85	58	73	7 - 8	
1—4	7-2	3.800	2.000	2.900	2	89	58	74	7 - 8	
300—14	7-15	5.900	1.950	3.421	7	85	55	73	7 - 8	
				Adult females—*M. femur-rubrum*						
9—14	6-24	2.760	1.800	2.280	2	92	65	84	7 - 8	
9—14	6-24	1.050		1.050	1	92	65	84	7 - 8	
	7-1	3.780	2.060	2.920	2	92-95	constant temp.			
	7-5	4.000	3.500	3.750	2	"	"	"		
				Adult males—*M. femur-rubrum*						
	7-1	1.860	1.580	1.720	2	92-95	constant temp.			
	7-5	2.170	1.820	1.995	2	"	"	"		

AMOUNT OF FOOD EATEN BY GRASSHOPPERS WHEN FEEDING ON DIFFERENT FOOD PLANTS

Elsewhere in this paper it is shown that different food plants, such as alfalfa and lettuce apparently have no effect on the rate of development of grasshoppers, but there is an enormous difference in the amount eaten when expressed either by green weight or in square inches of leaf surface. As already shown the amount eaten by different individuals and the amount eaten by the same individuals vary from day to day even when the grasshoppers are kept under apparently indentical conditions, therefore we should have the ratio between different food plants varying slightly from day to day. This always occurs. Speaking in broad terms, *M. bivittatus, M. differentialis* and *M. femur-rubrum* feeding under the same conditions all eat from 3 to 4 times as much lettuce as alfalfa per day, when the quantity is expressed either in green weight or in square inches of leaf

surface. Comparative studies of Tables 5 and 6 show indications of this variation.

In an experiment in which comparative studies were made for the first 4 instars with individuals of *M. bivittatus* and *M. femur-rubrum* the following results were obtained: A total of 35 individuals of *M. femur-rubrum* feeding on alfalfa and 34 on lettuce, over a period of ten 12-hour feeding days in which the mean hourly temperature ranged from 70.2 to 79.5 degrees F., the ratio of the amount of alfalfa to lettuce eaten varied from 1:2.3 to 1:7.5 with an average of 1:4.9 for all instars. With *M. bivittatus* in which a total of 63 individuals were fed on alfalfa and 96 on lettuce, over a period representing eleven 12-hour feeding days in which the mean hourly temperature varied from 70.2 to 82 degrees F., the ratio of alfalfa to lettuce varied from 1:1.9 to 1:5.3, with an average of 1:3.4.

It is difficult to account for the entire amount of variation. To do so it would be necessary to know to what extent a grasshopper was capable of digesting the nutrients in each material utilized. The following figures give the general analysis for alfalfa and lettuce:

	Alfalfa*	Lettuce**
Water	74.7 percent	94.0 percent
Ash	2.4 "	0.9 "
Crude protein	4.5 "	1.2 "
Fat	1.0 "	0.3 "
Carbohydrate	10.4 "	2.9 "
Fiber	7.0 "	0.7 "

*Analysis by Henry and Morrison (83)
**Analysis by Sherman (84)

According to the above analyses, alfalfa contains 4.26 times as much dry matter as lettuce, 3.7 times as much protein, 3.5 times as much carbohydrate, 3.3 times as much fat, 2.6 times as much ash and 10 times as much fiber. Alfalfa and lettuce leaves of equal thickness weigh approximately the same per square inch of leaf surface. Thus, it would appear that the percentage of nutrient material in each food would account for most of the difference in the amount eaten.

Waste Occurring When Feeding

Everyone observing the feeding habits of grasshoppers has noticed the enormous waste that occurs by the biting off of parts of the plant which fall to the ground and are never eaten. To make a study of this in a comparative way is difficult, due to the many variable factors that must be considered. Males and females never eat the same amount of food; the amount of food

eaten at different temperatures is never the same, and due to the difference in size of the grasshoppers and the quantity of food consumed, small nymphs do not waste as much as large nymphs and adults. All these factors cause a variation in waste and since they must be considered, the problem is extremely complex.

An elementary study was made by the writer on the amount of waste occurring on alfalfa by adult females of *M. bivittatus*. Fifty adult females over a period of 12 hours, from 7 a. m. to 7 p. m., at a mean hourly temperature of 80 degrees F., destroyed 26.352 grams of green alfalfa of which 4.404 grams were cut and never eaten. This is 16.7 percent of the amount destroyed.

THE EFFECT OF THE LENGTH OF DAY ON FEEDING

The length of day, providing the temperature remains within the limits of activity, should affect the feeding operations of grasshoppers. These facts are generally known, but there are few records in literature which give specific information on this question. In the case of grasshoppers, the question is of economic value since control is based to a great extent on the feeding habits.

Experimental evidence shows that high mean hourly temperature is conducive to an increased metabolic activitiy and rate of food consumption. Temperature is often one of the factors which limits feeding during a day. During summer there can be found in Colorado, days which have temperatures that would permit long hours of feeding.

Results obtained in a study of daily food habits indicated that the length of day has a special significance in the amount of food consumed by grasshoppers, so an experiment was performed to obtain definite data covering this point.

Three species of grasshoppers *M. bivittatus, M. differentialis* and *Chortophaga viridifaciatus* were studied. Several stages in their development, including males and females were considered. The insects were fed under constant temperature and light conditions for a period of 24 hours. A constant temperature of 95 degrees F. was employed. The amount of food eaten was recorded at 12- and 24-hour intervals. The summarized results indicated that the length of feeding day has an important bearing on the quantity of food a grasshopper will eat. Feeding occurred over the entire 24-hour period, and the amount of food eaten was greatly increased. There was some range of variation for individuals, some individuals increasing the quantity eaten but slightly over the 12-hour period, while others more than doubled the quantity.

These variations are to be expected since on any day there is a decidedly wide range as to the feeding activities of individuals.

In summarizing a series of 6 experiments in which 40 individuals were studied it was found that there was an average of from 56.7 to 74.6 percent increase in the 24-hour day over the 12-hour.

The detailed results are given in Table 7.

Table 7.—Notes on the Amount of Food Consumed in Square Inches During Long and Short Days by Grasshoppers. Constant Temperature 95 Degrees F. Food plant—Lettuce

Exp.	Date 1927	Amount food consumed in 12 hours 8 a. m. - 8 p. m. Max.	Min.	Ave.	Amount food consumed in 24 hours— Light 24 hours 8 a. m. - 8 a. m. Max.	Min.	Ave.	Number Grasshoppers	Amount increase over 12 hours	Percentage increase over 12 hours
					Chortophaga viridifaciatus First instar					
1	7-15	.065	.045	.051	.120	.060	.082	14	.031	60.7
2	7-18	.115	.057	.083	.200	.092	.145	14	.062	74.6
					M. bivittatus Sixth instar					
3	7-15	7.800	4.540	6.170	10.520	9.480	10.000	2	3.830	62
4	7-18	5.300	1.950	3.665	11.300	2.950	6.027	4	2.362	64.4
					M. differentialis—Males					
5	8-3	5.350	2.580	3.965	8.450	3.980	6.215	2	2.250	56.7
					M. differentialis—Females					
6	8-3	4.660	2.650	3.750	8.660	2.650	6.074	4	2.325	62

Moulting and Its Effect on Feeding

Shortly before a grasshopper moults there is a rapid decline in the amount of food eaten. Usually it does not eat the day prior to moulting. The number of hours between the time feeding ceases and the skin is shed will vary. High temperatures shorten the time considerably. Often there is a period of 24 hours or more in which no feeding takes place. Immediately after moulting grasshoppers do not eat for several hours, but will begin to eat soon after the chitin hardens.

It is rather difficult to correlate the moulting with poor results that are often obtained with poisoned-bran mash. It is known that nymphs hatched on the same day and from the same egg pod under field conditions will vary in their size and moulting dates before reaching maturity. In a field containing a large number of nymphs hatched at approximately the same time there will be a peak in the curve representing their dates of

moulting. At this peak it appears plausible to believe that poisoned-bran mash would be least effective. If only 25 percent of the grasshoppers moulted on this date, the efficiency of the bait would be materially affected. Regardless of time of hatching, this must be considered as one of the factors which reduce the efficiency of bait. In the laboratory studies this was a big factor in the average rate of food consumption for a series. Fasting on the day before and the day of moulting was always very noticeable. Often an individual would not eat for 2 days during the moulting period.

DIFFERENCE IN THE RATE OF FOOD CONSUMPTION BETWEEN ADULT MALES AND FEMALES

Adult females are larger than males and it would be natural for them to eat greater quantities of food. In addition to this they must eat to produce the large number of eggs which they lay. Males must also eat to produce the sperms as well as to maintain their bodies.

However, after considering the difference in body weight and size of males and females it appears that more food is required for egg production than sperm production. The difference in the amount of food eaten by the sexes is great. On comparing 113 males against 94 females, it was found that the females ate from 1.8 to 3.6 or an average of 2.5 times more food than males in a 12-hour day. Computing this on the basis of percentage, the females of this series ate from 80 to 260.5 percent more food per day than the males. Table 8 gives the details.

Table 8.—A Comparison of the Amount of Food Consumed Daily by Adult Male and Female Grasshoppers.

Exp.	Date	Species	Ave. amount food consumed sq. in. Males	Ave. amount food consumed sq. in. Females	Number grasshoppers Males	Number grasshoppers Females	Percentage increase*	Food plant
1-1	6-20-27	M.b.**	.950	1.840	52	42	93.6	Alfalfa
1-4	6-17-27	"	1.775	6.400	2	2	260.5	Lettuce
1-4	7-2-27	"	2.900	5.266	2	3	81.5	"
1-4	6-30-27	"	1.780	5.843	2	3	228.1	"
27	10-22-26	"	.720	2.146	20	20	198	Alfalfa
2-2	5-5-27	C.v.	.643	1.705	9	4	165.1	Lettuce
2-4	7-1-27	M.f.r.	1.851	3.335	4	4	80.1	"
2-3	6-23-27	M.b.	2.666	5.950	20	14	123.1	"
1-4	6-24-27	"	3.225	7.260	2	2	125.1	"

*Percentage increase of females over males.

**M.b.—*Melanoplus bivittatus.*

C.v.—*Chortophaga viridifaciatus.*

M.f.r.—*Melanoplus femur-rubrum.*

DIFFERENCE IN THE AMOUNT OF FOOD EATEN BY DIFFERENT SPECIES

To obtain an index of the differences in the amount of food eaten by adults of different species, a comparison was made with *Melanoplus bivittatus, M. differentialis* and *M. femur-rubrum.*

As size would indicate, the difference in the amount eaten is quite noticeable between the large and small species. *Melanoplus bivittatus* and *M. differentialis,* the 2 larger species, eat approximately the same amount with slight variations, while *M. femur-rubrum* eats considerably less. It is not uncommon to find females of *M. bivittatus* eating from 4 to 7.5 square inches of lettuce during a 12-hour day. *M. femur-rubrum* under the same conditions, will eat from 2 to 4 square inches. The same condition occurs in the males, *M. bivittatus* commonly eating from 2.5 to 5 square inches and *M. femur-rubrum* eating from 1.5 to 2 square inches of lettuce under the same conditions. Comparative studies made with males of *M. differentialis* and *M. femur-rubrum* under constant temperature of 95 degrees F. for a 12-hour period showed that the former avereaged 3.750 square inches of lettuce and the latter averaged 1.857 square inches.

A study of the average amount of food consumed during a 12-hour day for all individuals under temperature conditions from 68 to 95 degrees F. showed that females and males of *M. bivittatus* average 5.95 and 2.66 square inches of lettuce respectively while *M. femur-rubrum* averaged 2.50 and 1.85 square inches.

The above is a significant factor when considering grasshopper damages. A field infested with *M. bivittatus.* or *M. differentialis* will suffer twice the loss each day that it would if infested with one of the smaller species such as *M. femur-rubrum* in the same numbers.

THE EFFECT OF AGE OF ADULT ON FOOD CONSUMED

As long as the adults are active and producing eggs or sperms, the rate of food consumption found in newly emerged adults appears to be maintained for a period of at least 30 days. Table 9 shows this for both males and females of *M. bivittatus.*

Table 9.—Showing Relative Rate of Food Consumption over a Period of 30 Days for Adults.

Food plant—Lettuce

Date	Female number	Female number	Male number	Male number	Temperature Min.	Max.	Mean
1927	1	4	2	3			Hourly
5-31			.820		54	79	70
6-1			2.750		60	87	76
6-7			3.700		70	88	81
6-12			2.740		58	89	74
6-17	6.680	6.120	1.870	2.420			
6-23	4.820	4.760	2.000	5.110			
6-24	7.000	7.52	1.841	4.610	65	93	83
6-30	5.720	7.010	1.210	2.350			
7-2	6.000	5.900	2.000	3.800			

Grasshoppers collected from the field that gave indications of being very old ate equally as much as young adults under the same conditions. This was shown by the following experiment: In the fall of 1926, a series of old males and gravid females of *M. bivittatus.* was collected for study. The battered condition of the wings gave evidence of their age. On October 22, 20 females and 19 males were fed alfalfa individually and results recorded. The females ate an average of 2.126 square inches each while the males ate an average of 0.757 square inches each. The temperature ranged from 64 to 77 degrees F. with a mean hourly temperature of 69.6 degrees F. This amount is equal to as much as newly emerged males and females would eat under the same conditions.

NUMBER OF FEEDING PERIODS DURING A DAY

If a day is divided into 12 feeding periods of 1 hour each, a knowledge of the number of these periods in which a grasshopper will take food is of value in estimating the chances it has of being poisoned with bait. Experimental evidence indicates that the number of periods is very variable. Such factors as temperature and kind of food available seem important.

With regard to temperature, as stated before, very little feeding occurs below 65 to 68 degrees F. Above these temperatures the amount of food consumed, as well as the number of feeding periods, increase.

The kind of food plant also causes a wide variation in the number of feeding periods during the day. Animals given identical conditions except for difference in food show a distinct variation. Table 10 shows the effect of lettuce and alfalfa on the frequency of feeding as indicated by a study of 559 individual grasshoppers of *M. bivittatus.*

Table 10.—Notes on Number of Feeding Periods During a Day for *Melanoplus bivittatus*.

Date	Exp.	Number grass-hoppers	Number hourly feeding periods Total	Min.	Max.	Ave.	Temperature Fahr. Max.	Min.	Mean	Food	Length of day a.m.-p.m.
					First instar						
5-16-27	200	13	50	1	6	3.8	85.5	59	70.6	Lettuce	7 - 7
5-17-27	300	13	97	5	8	6.9	89	60	78.2	"	7 - 7
5-18-26	10	8	15	1	4	1.9	64.5	48.5	57.5	Alfalfa	6 - 6
5-18-26	11	9	25	1	4	2.8	87	67	74.5	"	6 - 6
5-21-26	12	5	17	1	6	3.4	90	64	77.5	"	5 - 7
					Second instar						
5-25-27	200	13	66	2	6	5	89	51	75.3	Lettuce	7 - 7
5-23-27	300	12	68	2	8	5.6	85	50	71.4	"	7 - 7
5-25-27	300	12	82	5	11	6.8	87	61	78.9	"	7 - 7
5-25-27	100	9	38	2	6	4.2	87	61	78.9	Alfalfa	7 - 7
7-23-26	26	8	28	2	6	3.5	80	58	69.6	"	5 - 8
					Third instar						
6-1-27	200	13	94	3	11	7.2	87	60	79	Lettuce	7 - 7
6-2-27	300	11	71	5	8	6.4	89	61	72	"	7 - 7
6-1-27	100	9	48	3	7	5.3	87	60	79	Alfalfa	7 - 7
6-2-26	14	8	22	1	6	2.8	80	58	71	"	6 - 7
6-20-26	21	10	31	1	5	3.1	84	57	72	"	5 - 8
					Fourth instar						
6-17-27	200	10	53	1	9	5.3	83	58	74.5	Lettuce	7 - 7
6-17-27	300	11	68	1	9	6.1	83	58	74.5	"	7 - 7
6-17-27	100	9	29	1	6	3.2	83	58	74.5	Alfalfa	7 - 7
					Fifth instar						
6-30-27	200	8	41	2	10	5.2	85	58	74.2	Lettuce	7 - 7
6-30-27	300	6	30	2	9	5	85	58	74.2	"	7 - 7
6-30-27	100	5	18	1	6	3.6	85	58	74.2	Alfalfa	7 - 7
7-20-26	22	18	61	1	6	3.4	84	57	72	"	5 - 8
7-23-26	25	18	59	1	5	3.3	80	58	69.6	"	5 - 8
					Adult males (Young)						
7-20-26	23	17	55	1	6	3.2	84	57	72	"	5 - 7
7-23-26	24	17	49	1	7	3	80	60	69.6	"	6 - 8
					Adult males (Old)						
10-22-25	27	19	32	1	4	2	78	64	69.4	"	8 - 5
10-25-26	30	17	39	1	4	2.3	79	65	74	"	8 - 5
10-22-26	31	15	31	1	4	2	78	62	71.6	"	8 - 5
10-27-28	33	16	34	1	4	2.1	78	66	73.3	"	8 - 5
10-28-26	35	16	30	1	4	2	72	65	69.1	"	8 - 5
10-29-26	37	25	65	1	7	2.6	66	48	61.7	Rose Leaves	8 - 5
					Adult females (Gravid)						
10-22-26	29	20	78	1	6	3.9	78	64	69.4	Alfalfa	8 - 5
10-25-26	29	32	133	1	7	4.1	79	65	74	"	8 - 5
10-26-26	32	38	141	1	7	3.7	78	62	71.6	"	8 - 5
10-27-26	34	28	116	1	6	4.1	78	66	73.3	"	8 - 5
10-28-26	36	28	84	1	5	3	72	65	69.1	"	8 - 5
10-29-26	38	14	24	1	3	1.7	66	48	61.7	Rose	8 - 5
11-5-26	39	19	67	1	5	3.5	82	62	71.2	Four O'clock	8 - 5

Average Number of Feedings per day on lettuce 5.7.
Average of Number of Feeding per day on alfalfa 3.2.

Grasshoppers feeding on lettuce ate during a greater number of periods than those feeding upon alfalfa. This was to be expected as grasshoppers consumed greater quantities of lettuce both by weight and volume than alfalfa. The average number of periods in which feeding occurred for 559 individuals feeding under the varying temperature conditions of the experiments was 5.7 for lettuce and 3.2 for alfalfa. The maximum was 11 periods for lettuce against 7 for alfalfa. (Figure 6 gives evidence of the greater number of times feeding occurs on lettuce than on alfalfa.) The grasshoppers in this experiment were under the same environmental conditions except for food. In each case all of the grasshoppers ate during the day, but the percentage feeding each hour was much greater on lettuce than on alfalfa.

TIME UTILIZED FOR EATING

The time required, the amount eaten, the time feeding occurs and the number of individuals feeding are important factors and have a bearing on control recommendations for grasshoppers.

Studies were made to determine the total time utilized for feeding during a 1-hour period. There was considerable individual variation during any one period, as well as a variation from period to period. In a study of adult gravid females of *M. bivittatus* it was found that the time varied from 3 minutes to as much as 49 minutes and 20 seconds. For 25 grasshoppers observed the average was 16.1 minutes. There were times when feeding would not last for any noticeable length of time, the grasshoppers taking only 1 or 2 bites and not feeding further. The details of this series of experiments are shown in Table 11.

Studies were also made of nymphs ranging in age from the first to fifth instar. Grasshoppers in the above-mentioned stages varied the total time used to eat during one period from 2 to 23 minutes.

According to the above one can see that grasshoppers spend only a relatively small portion of the day feeding. To illustrate this: Take the maximum number of periods feeding occurred in any experiment, which was 7 for alfalfa and 11 for lettuce. Then allowing 16 minutes for each feeding period, one finds that in a 12-hour day with the temperature ranging between 70 and 90 degrees F. a grasshopper on lettuce spends 2 hours and 56 minutes at actual feeding, while a grasshopper on alfalfa spends only 1 hour and 52 minutes.

Table 11.—Time Utilized by Adult Gravid Females *M. bivittatus* to Eat During a 1-hour Period and Amount of Leaf Surface Consumed.
Food plant—Lettuce

Exp.	Time utilized at feeding	Time feeding began	Temp. at which feeding began	Leaf area consumed during feeding period	Date
2	3 Min.	8:45 a. m.	69 Fahr.	.31	10-22-26
1	12 " 30 Sec.	9:17 "	72 "		10-21-26
3	12 " 46 "	9:45 "	73 "	1.00	10-21-26
4	10 " 40 "	10:52 "	76 "	1.25	10-21-26
5	9 "	10:32 "	76 "	.95	10-21-26
7	7 " 45 "		70 "	1.12	10-21-26
8	14 " 15 "		70 "	1.50	10-21-26
10	49 " 20 "	8:26 "	64-69 "	.90	10-22-26
13	10 " 50 "	8:25 "	64-69 "	.64	10-22-26
17	13 " 30 "	8:20 "	64 "	.88	10-22-26
18	8 "	8:20 "	70 "	.83	10-23-26
1a	4 " 42 "	11:20 "	79 "	.41	10-25-26
2a	27 "	11:30 "		1.55	10-25-26
3a	15 "	2:30 p. m.	73 "	.80	10-25-26
22	18 " 55 "	8:20 a. m.	70 "	1.30	10-26-26
23	4 " 50 "	8:25 "	70 "	.20	10-26-26
24	3 " 20 "	8:23 "	70 "	.25	10-27-26
25	13 " 21 "	8:35 "	72 "	.91	10-28-26
26	16 " 30 "	2:20 p. m.	69 "		10-28-26
27	9 " 15 "	2:21 "	69 "		10-28-26
28	30 "	9:06 a. m.	70 "		11-3-26
29	7 " 10 "	9:05 "	70 "		11-3-26
30	5 " 25 "	9:10 "	70 "		11-3-26
31	8 "	10:30 "	78 "	.15	11-3-26
32	5 " 16 "	10:00 "	71 "	.65	11-3-26

The above figures probably vary from those that would actually be encountered in the field, but indicate the approximate time spent during a day in food consumption.

In the course of a comparatively short period grasshoppers are capable of consuming large quantities of food. For example on October 11, 1926, 1 adult female of *M. bivittatus*. was observed to eat 1.12 square inches of lettuce in 7 minutes and 45 seconds at a temperature of 70 degrees F. However, as a rule, the amount eaten in the above time is somewhat less.

A Comparison of Different Food Plants on Rate of Development

An attempt was made to gain information relative to the rate of development on different food plants. Since there was a wide variation in the amount of leaf surface eaten by the same species of grasshoppers when feeding on different plants, it occurred to the writer that this difference might cause some variation in the rate of development. Even if the dry weight food

value was the same, it appeared possible that the process of caring for the excess bulk and water might so affect the metabolic rate that a variation would occur. With this in mind 2 species of grasshoppers, *M. bivittatus,* and *M. femur-rubrum,* were selected and reared. The grasshoppers were kept under apparently identical conditions, except for food. One series was fed entirely upon alfalfa, the other entirely upon lettuce. The grasshoppers were fed daily and notes made upon moults and conditions of development. In the first experiment 12 individuals of *M. femur-rubrum* were used. In the second experiment 24 individuals of *M. bivittatus* were used. Table 12 gives a summary of the results obtained.

Table 12.—Comparison of Different Food Plants on Rate of Development.

Exp.	Average number days for each instar					Number days required for development		
	1	2	3	4	5	Max.	Min.	Ave.
				M. femur-rubrum				
				Plant food—Lettuce				
1	10.8	10.6	9.4	12	19.6	65	59	62.4
				M. femur-rubrum				
				Plant food—Alfalfa				
1	11.2	13.6	12.4	14.6	16.4	77	64	68.2
				M. bivittatus				
				Plant food—Lettuce				
2	10	8.5	11	10.7	13	60	49	53.2
				M. bivittatus				
				Plant food—Alfalfa				
2	10.5	8.5	9.5	11	15.2	64	51	54.7

At first glance it appears that the grasshoppers *M. femur-rubrum* in the first experiment developed more rapidly on lettuce than alfalfa. The average for all shows that the individuals feeding on lettuce completed 5 instars in 62.4 days while those feeding on alfalfa required 68.2 days, a difference of 5.8 days. A further study of the data shows that there was considerable overlapping in the development, so that some of the individuals feeding on alfalfa developed apparently as fast as some of those feeding on lettuce. This would indicate that there is probably little, if any, difference in the rate of development on the 2 food plants. Since there is a wide range in the rate of development of individuals, the difference could probably be accounted for in experimental error as there were only 12 individuals in the series.

This can be further illustrated by the fact that, in a series of experiments on the development of *M. differentialis* under identical food conditions and at a constant temperature of 95 degrees F., there was considerable variation in the rate of devel-

opment. All individuals of this series reached maturity in an average of 24.7 days. The minimum time required for growth was 22 days with a maximum of 32 days, thus giving a variation of 10 days.

In the second experiment, 24 individuals of *M. bivittatus* were used. The method of experimentation was the same as for the *M. femur-rubrum*. Those grasshoppers feeding on the lettuce developed thru 5 instars in an average of 53.2 days while the average for those fed alfalfa was 54.7 days, a difference of 1.5 days in favor of those fed lettuce. As in the preceding experiment, there was considerable overlapping in the rate of development. Many of the individuals feeding on alfalfa developed as quickly as those feeding on lettuce.

The average difference in the rate of development for the 2 series is small and it is entirely possible that the variation is within experimental error, or even within individual variation as has been illustrated.

THE EFFECT OF LIGHT ON DEVELOPMENT

Since all our common injurious grasshoppers are active almost entirely during daylight and are phototrophic, that is they respond toward light, one would conclude that light is essential to food consumption and development. The fact that activity in nature usually ceases when night approaches, would seem to confirm the above conclusion.

During the season of grasshopper development the hours of daylight vary to some extent. The writer, thinking this might have some effect upon development, made this study.

In an effort to determine the effect of light, if any, on the rate of development in *M. differentialis*, 2 sets of experiments of 20 grasshoppers each were begun. In experiment 1 the temperature was held to 92 to 95 degrees F., and one-half of the grasshoppers were exposed to light for 24 hours. During the night, light was furnished by a 75-watt electric lamp. The remaining one-half of the grasshoppers were given light only 12 hours during the day and then placed in complete darkness. In the second experiment the same arrangement as in experiment 1 was followed except that at night instead of being exposed to a temperature of 92 to 95 degrees F. the grasshoppers were exposed to natural temperature. The results were based on the average of those grasshoppers surviving 5 instars.

The grasshoppers in experiment 1 exposed to 12 hours of light developed thru 5 instars in an average of 23.6 days, while those exposed to 24 hours of light developed in and average of 25.1 days.

In the second experiment a reverse of the conditions of experiment 1 occurred. The insects having 24 hours of light developed in an average of 32.4 days while those exposed to only 12 hours of light developed in an average of 36 days.

Considering the number of grasshoppers in the experiment, it is entirely possible to account for the above variation by individual variation in growth. It is known that grasshoppers reared under apparently identical conditions will vary considerably in their rate of growth. Therefore, from the above results it would seem that light does not affect the rate of growth under the above-named conditions. Table 12 shows the details of the experiment.

In caring for these experiments it was observed on numerous occasions that grasshoppers would eat in complete darkness when the temperature was sufficiently high. Not only would they eat but they would also moult and grow.

Table 13.—A Study of the Effect of Light Upon the Development of *M. differentalis.*

A.—Constant temperature of 92-95 degrees F.; light for 12 hours and darkness for 12 hours.

Individual	Date hatched 1927	Moults First	Second	Third	Fourth	Fifth	Days required to develop 5th instar
1	6-3	6-9	6-13	6-17	6-21	6-27	24
3	6-3	6-9	6-13	6-16	6-23	6-29	26
7	6-3	6-9	6-14	6-17	6-21	6-26	23
9	6-3	6-9	6-13	6-17	6-20	6-26	23
10	6-3	6-9	6-13	6-17	6-21	6-25	22
Average							23.6
B.—Constant temperature 92-95 degrees F.; constant light 24 hours.							
12	6-3	6-9	6-14	6-17	6-20	6-26	23
14	6-3	6-9	6-15	6-18	6-21	6-26	23
15	6-4	6-12	6-16	6-19	6-25	7-6	32
17	6-3	6-9	6-12	6-16	6-19	6-25	22
18	6-4	6-11	6-17	6-20	6-25	7-2	28
50	5-31	6-7	6-10	6-14	6-18	6-23	23
Average							25.1
C.—Constant temperature 92-95 degrees F. 12 hours; natural temperature at night 12 hours, light 24 hours.							
22	6-4	6-11	6-17	6-21	6-27	7-4	30
23	6-4	6-11	6-17	6-22	6-27	7-4	30
24	6-4	6-11	6-17	6-20	6-26	7-2	28
25	6-4	6-11	6-17	6-20	6-26	7-4	30
26	6-4	6-11	6-17	6-21	6-26	7-6	32
1x	5-29	6-9	6-14	6-20	6-24	Lost	
2x	5-29	6-10	6-15	6-20	6-26	7-2	34
3x	5-29	6-10	6-15	6-20	6-25	7-6	38
4x	5-29	6-9	6-14	6-20	6-25	7-1	33
5x	5-29	6-9	6-14	6-20	6-26	7-5	37
Average							32.4

D.—Constant temperature 92-95 degrees F. 12 hours; natural temperature at night 12 hours; light 12 hours; darkness 12 hours.

30	6-4	6-11	6-17	6-22	6-27	7-15	31
33	6-4	6-11	6-17	6-23	6-29	7-22	48
38	6-4	6-11	6-17	6-21	6-29	7-7	33
39	6-5	6-12	6-17	6-23	6-29	7-7	32
Average							36

ACTIVITIES IN DARKNESS

Riley (60) states that *M. spretus* does not feed at night during cool weather, but when the weather is warm and dry it is often as ravenous during the night as during the day. He also gives evidence that there were times when flights occurred at night. He stated that Gerstaecker reported that the European *migratoria* fed mostly at night.

Usually the common injurious species of grasshoppers in Colorado exercise little or have no activity at night. They are usually found motionless in their characteristic roosting positions. Parker (54) has shown that for *Camnula pellucida* in Minnesota, this phenomenon can be correlated with temperature. He also shows that it is not a light reaction since the time when roosting begins in the field depends upon the temperature rather than the hour.

The writer in his work noticed that occasionally feeding occurred at night. As a result an experiment was started to determine the effect darkness would have upon activity.

During June, 1927, 2 series of experiments were made in which 20 second instar *M. bivittatus* were used. In one set the grasshoppers were kept in complete darkness. In the other the grasshoppers were exposed to normal conditions as afforded by daylight. Both experiments were kept under the same conditions except for light. The temperature was maintained above 70 degrees F. At the end of 24 hours the amount of food eaten was measured. Those grasshoppers kept in complete darkness consumed an average of .168 square inches of lettuce each. The maximum amount eaten by one individual was .234 square inches and the minimum amount was .058 square inches. Those individuals fed under normal light conditions ate an average of .139 square inches of lettuce, with a maximum of .124 and a minimum of .093 square inches.

This indicates that when the temperature is within the range of activity a grasshopper will eat in darkness and at night as well as in the daylight. Numerous other observations in which comparisons were not made bear out this conclusion.

Another test was made in which grasshoppers were reared in complete darkness except for the few minutes each day that

was required to place food in the cage. It was found that *M. bivittatus* will eat, grow and moult when kept in complete darkness. No extensive comparisons were made of the effect that darkness had on the rate of development but preliminary comparison was made between the first and second moults. The series given normal conditions required an average of 11.6 days to pass from the first to the second instar. The maximum number of days was 14 and the minimum 9 days. Those kept in darkness averaged 10.1 days with a maximum of 13 days and a minimum of 9 days. This would indicate that the rate of development was about the same. Elsewhere in this paper it is shown that the rate of development is essentially the same under continuous light as it is under intermittent darkness of 12 hours and light 12 hours. This would tend to further confirm the above. Temperature records were not kept over the entire period of the experiment but the grasshoppers completed their growth in an average period of 67 days.

According to these results it appears safe to predict that under favorable conditions grasshoppers will eat and cause losses during the entire 24 hours of the day. However, in Colorado, with its cool nights, grasshoppers do not normally feed during the entire night. Feeding probably occurs only during those hours of the night when the temperature is above 68 degrees F.

ECONOMIC ASPECTS OF THE RESULTS

An analysis of results obtained in this research indicates that the following factors are of economic importance:

Temperature is an important factor in reproduction, development and feeding habits. These activities are closely associated with the economic status. High mean daily temperatures are conducive to rapid development, which indicates that if other weather conditions are favorable a year with a combination of an early spring, hot summer and late fall is ideal for grasshopper development and maximum damage. Such conditions would cause early hatching of eggs as well as early maturity of the insects. Further, these conditions make maximum losses possible not only from the nymphs but from the adults, due to the favorable days which permit a long period over which feeding can occur. Egg production would also be at its maximum which would favor an outbreak the following year.

Since adults eat almost 100 times as much in a day as first instar nymphs, grasshoppers should be poisoned when they are in the nymphal stage. Poisoned bait should be applied during the period when activity is confined to the surface of the ground.

Bait should not be applied during specified hours, but only during those hours in the day, when the ground temperature is at least 68 degrees F. and less than 100 degrees F. After the ground temperature goes above 98 degrees F. poison should not be applied since grasshoppers have a tendency to climb vegetation and other debris to a comfortable temperature. After the grasshoppers leave the ground they do not feed on the bait on the soil surface but upon the vegetation on which they rest.

It would appear that the efficiency of the bait is determined by the number of hours that it is comfortable for the grasshoppers to feed at the surface of the ground. If the ground-feeding period is relatively short and universal feeding does not occur, control results are not apt to be as satisfactory as when this period is longer.

The morning hours are most desirable for the application of baits since at that time the ground-feeding periods are longest. The bait should be on the ground by the time the surface temperature reaches 68 or 70 degrees F. in order to permit as many grasshoppers as possible to feed upon it.

If bait is applied after the first general feeding period of the day is completed, the chances are that a high mortality will not be obtained due to the fact that the feeding periods of grasshoppers are of short duration. Moreover, the insects feed only during a small number of periods in the course of a day. This is regulated by the temperature and character of the food plant, altho the kind of food plant is likely to have an indirect bearing on the results obtained. For example, if the food is lettuce the chances should be greater for a high mortality than if the food is alfalfa because grasshoppers eat more often when feeding upon lettuce than on alfalfa. Thus the opportunities for being poisoned are increased.

When the insects are in the nymphal stage it appears that moulting may at times be a factor responsible for ineffective kills. Under ordinary conditions 1 to 2 days are lost during the moulting process. If a field containing nymphs of approximately the same age be poisoned during the moulting period, it is likely that a markedly inefficient kill will be obtained. It is known that all grasshoppers hatched on the same day do not moult at uniform periods, but if only 25 percent moulted on the same day the results in control might be very noticeable.

The species infesting a field will make a difference in the actual losses to the grower. *M. bivittatus* and *M. differentialis*, eat almost twice as much per day as *M. femur-rubrum*. Therefore an infestation of one of the larger species which equals in

numbers the smaller species will cause twice the loss of the smaller species.

If the temperature is sufficiently high, losses will occur during both day and night. Light appears to have no affect on feeding.

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AUTOBIOGRAPHY

I, George Shealy Langford, was born near Blythewood, South Carolina, March 9, 1901. I received my secondary education in the grade and high schools of Richland County. In 1917 after competitive examination, I was awarded a Scholarship, from South Carolina at large, to the Clemson Agricultural and Mechanical College, and entered that fall. Majoring in entomology, I received the Bachelor of Science Degree in 1921. During 1921-1922 I taught biology in the Lillington High and Farm-Life School, Lillington, North Carolina. From 1922 to 1924 I was an assistant in entomology at the University of Maryland, and from this institution received the Master of Science degree in 1924. In May, 1924, I accepted the position of Deputy State Entomologist in Colorado, which position I held until June, 1928. During 1927-1928 I was in residence at the Ohio State University as an assistant in Zoology. Since June, 1928, I have been stationed, on a fellowship, at the Ohio Experiment Station investigating the insecticidal properties of Shale Oil. I am a member of several Scientific organizations including Sigma Xi, Entomological Society of America, American Association of Economic Entomologists, and the Washington Entomological Society. I completed the requirements for the Degree of Doctor of Philosophy in June, 1929.